COLON MYOELECTRICAL AND MOTOR ACTIVITY WITH SPECIAL REFERENCE TO THE IRRITABLE BOWEL SYNDROME.

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ABSTRACT OF THESIS
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Silver-silver chloride electrodes attached to the abdominal skin of New Zealand White rabbits were evaluated as a method for detecting colonic myoelectrical activity. A comparison with electrodes implanted into the colon showed a close correlation in amplitude but not in frequency of the smooth muscle electrical slow wave. The source of the skin electrode potentials was located in the taenia coli, demonstrated by excision experiments. Further experiments by restricting gross movement of the bowel and artificially moving the colon revealed that physical movement of the bowel rather than myoelectrical events were responsible for the changes in potential detected by the skin electrodes.

In Section 2, motor activity of the rectosigmoid colon and rectum was studied in normal human volunteers and patients with the Irritable Bowel Syndrome (IBS). A new device was designed and constructed to measure contractions directly with the use of strain gauges mounted on a polyvinyl chloride tube. With this Strain Gauge Probe the following were identified:

Types of Contraction
Changes in smooth muscle tone
Distension and Deflation
Segmenting Contractions
Propagated Contractions
Direction of Propagation
Rate of spread of propagation

The IBS group was subdivided into the Constipation predominant and the Diarrhoea predominant groups. Studies of the motor activity showed that abdominal pain in the IBS was intimately related to segmenting contractions with a high amplitude. There was a significant increase in the rate of spread of propagated contractions in the Diarrhoea predominant IBS compared with the control group in the resting state. A less significant increase in rate of spread was detected in the Constipation predominant IBS group.

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INTRODUCTION.

Contractions of the colon serve two functions: firstly, propagated contractions move the luminal contents along the bowel and secondly, segmenting contractions divide the lumen into discrete segments, retarding the onward progression of faeces and allowing reabsorbtion of water and the products of bacterial fermentation to take place.

Alteration of these actions results in abnormalities of colon function, namely, diarroea or constipation, and abdominal pain as seen in the Irritable Bowel Syndrome or in Diverticular Disease.

The Irritable Bowel Syndrome (IBS) is a disorder of the intestinal tract characterised by abdominal pain and a disturbance of bowel habit (a detailed description is given in Section 2). It is an extremely common condition, affecting a younger group of the population in their productive years. Although it has a characteristic symptomatology, there are no routine investigations which demonstrate an abnormality. Hence it is a diagnosis made by excluding other relevant conditions. However, motility studies have demonstrated an abnormality in the colon in response to stimuli and it is this type of method which is used to investigate the IBS.

The muscular contractions of the intestinal muscle have their origin in the electrical activity which may be detected by electrodes placed within its substance. Two electrical rhythms have been recorded from human colonic smooth muscle, the lower frequency being more predominant

in the IBS. If a relatively simple method were available to record this electrical activity, it would be possible to make a positive diagnosis rather than a diagnosis by exclusion. A third of patients with the IBS have had an appendicectomy or gynaecological operation, the majority revealing no abnormality. This illustrates the diagnostic difficulty many of these patients present.

Skin electrodes have been used to detect the electrical activity of the intestinal smooth muscle, in particular the stomach antrum. This method is non-invasive in application and more acceptable to the patients undergoing motility studies.

The aim of Section 1 was:

1/.Evaluate skin electrodes as a method for detecting the electrical activity of the colonic smooth muscle.

The aim of Section 2 was:

2/.Develop a technique for recording intestinal contractions directly.

3/.Develop a method for detecting changes in human colonic smooth muscle tone.

4/.Identify propagated contractions, direction and velocity of propagation.

Anatomy of the Colon

The colon forms the terminal two metres of the gastrointestinal tract and connects the small bowel to the rectum and anus. Although the colon may be subdivided into caecum and appendix, ascending, transverse, descending and sigmoid colon, physiologically, the colon functions in two sections: these correspond to the terminal midgut or proximal colon, and the hindgut or distal colon, each with its own blood and nerve supply. The proximal colon includes the caecum, ascending and a variable portion of transverse colon with its blood supply from the superior mesenteric vessels. The distal colon is composed of the remaining transverse colon, descending, and sigmoid colon and terminates at the recto-sigmoid junction where the taenia coli merge to become circumferential. The distal colon receives its blood supply from the inferior mesenteric vessels.

Morphology.

Essentially a tube, the colon has a similar structure to other parts of the gastrointestinal tract. There are six layers:

1. Serosa - the outermost layer
2. Longitudinal muscle
3. Circular muscle
4. Submucosa
5. Muscularis mucosa
6. Mucosa - the innermost layer

One of the distinguishing features of the colon is the arrangement of the longitudinal muscle layer into three bands or taenia. There is

considerable shortening of the colon by the taenia which creates sacculations in the wall of the bowel by its concertina-like action.

Extrinsic Nerve Supply

The colon innervation is supplied by the Autonomic Nervous System. Parasympathetic nerves from the vagus nerve via the coeliac plexus supply the proximal colon and the pelvic splanchnic nerves supply parasympathetic fibres to the distal colon.

Sympathetic nerves, derived from postganglionic fibres from the coeliac, pre-aortic and superior mesenteric plexus, run along the blood vessels to supply the proximal colon, while post-ganglionic fibres from the presacral or hypogastric nerve supply the distal colon with sympathetic fibres.

Intrinsic Nerve Supply

There are two plexus of nerves situated between the muscle layers. The myenteric or Auerbach's plexus is situated between the outer longitudinal and inner circular muscle layer and the submucosal or Meissner's plexus lies between the circular muscle and muscularis mucosae. The extrinsic nerves do not synapse directly onto the smooth cells but with the cell bodies of the myenteric plexus.

The intrinsic innervation of the colon is complex and there is increasing evidence of three types of nerve:

	Neurotransmitter	Effect on Smooth Muscle
Cholinergic	Acetylcholine	Excitatory
Adrenergic	Noradrenaline	Inhibtory
Peptidergic	Substance P	Excitatory
	Vasoactive Intestinal Polypeptide (VIP)	Inhibitory
	Enkephalin	Inhibits transmural stimulation
	Somatostatin	Inhibits transmural stimulation

and possibly also:

Pancreatic Polypeptide

Angiotensin

Adrenocorticotrophic Hormone (ACTH)

Gastrin-cholecystokinin

Bombesin

The intramural neurones mediate and modulate the response to intrinsic nervous stimulation and may also be involved in local reflex mechanisms. Many of the peptidergic neurones serve as sensory neurones or as inter neurones (Sundler et al, 1980)

Smooth Muscle

Smooth muscle is distinguished from cardiac and skeletal muscle by the absence of visible striations on light microscopy. There are two kinds of smooth muscle, of which we are concerned with the latter:

1. Multiunit smooth muscle is found in the iris of the eye

where fine controlled contractions are required.

2. Visceral smooth muscle occurs in hollow viscera, such as the gastrointestinal tract, uterus, ureters, vas deferens and bladder. The size of the individual muscle fibre is unknown although it appears that they function in bundles of approximately 100 microns in width, (Burnstock and Prosser, 1960).

Intercellular connections.

The intestinal smooth muscle resembles cardiac muscle in that it has inherent contractions independent of nerve supply. The electrical activity spreads from one muscle cell to another and the rate of spread is slow, (Christensen, 1972) compared with cardiac muscle, although both function in a syncitial manner i.e. as if the cytoplasm of each cell were in contact with each other. In smooth muscle, this electrical contact occurs at the nexus, or intercellular junction (Dewey & Barr, 1962, Oosaki & Ishii, 1964) (Figure 1). The outer layer of the cellular membrane is fused in the area of the nexus (A-B) and there is no intervening extracellular fluid. There is little potential difference across the nexus and little resistance to the transmission of the depolarisation wave from cell to cell.

ELECTROPHYSIOLOGY

Membrane Potential.

A potential difference exists across the smooth muscle cell membrane, the cytoplasm being negative with respect to the extra cellular fluid. Although rarely static, this resting potential has been measured in the guinea pig taenia coli at -50mV (Holman 1958).

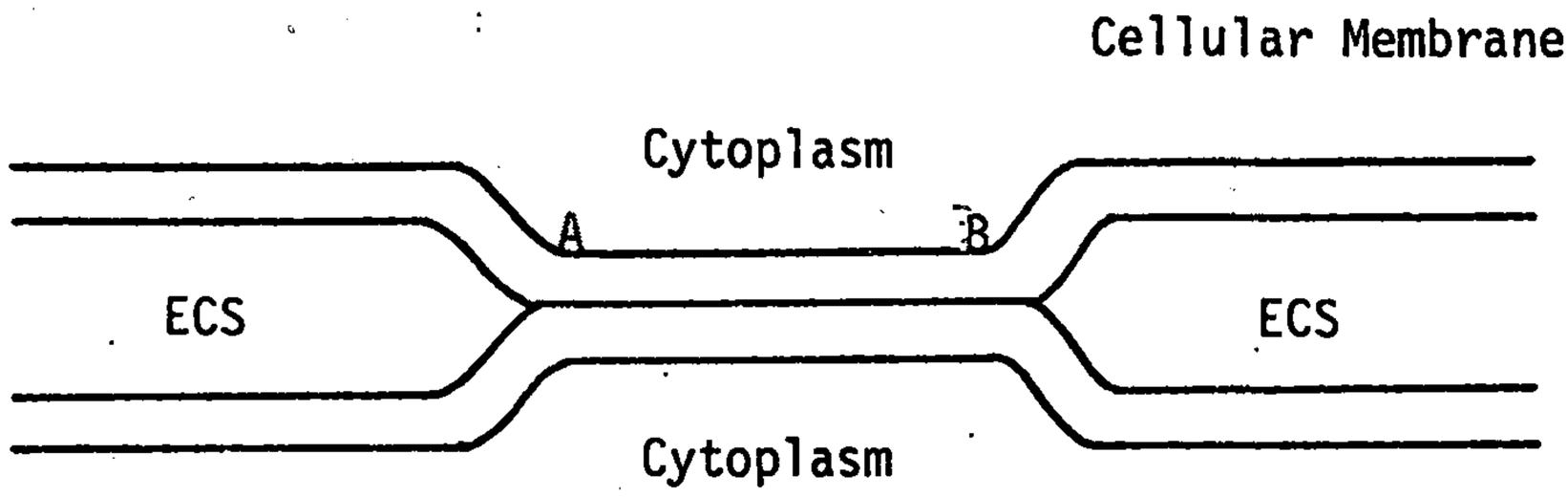


Figure 1. Diagram of the Nexus or tight inter-cellular connection.

The cytplasm of the smooth muscle cells is usually separated by seven layers (2 cell membranes and the Extracellular Fluid). At the Nexus, between points A-B, the outer cell membranes fuse resulting in five layers separating the cytoplasm of the two cells. It is thought that the nexus provides low resistance pathways between the smooth muscle cells for the transmission of electrical activity.

ECS - Extracellular Space.

(Reproduced from Dewey and Barr,
Intercellular connection between smooth muscle cells.
SCIENCE, 1962, 137, 670-672).

Ionic Basis of the Membrane potential.

The potential difference across the smooth muscle membrane is due to the distribution of ions on either side of the membrane, especially the distribution of sodium and potassium ions. Table 1 shows this distribution:

	Extracellular Fluid mMol/litre	Intracellular Fluid mMol/litre
Sodium	140-155	30-70
Potassium	4.5-5.5	180-200

Table 1. Distribution of sodium and potassium ions across the cell membrane of the smooth muscle cell.

The resting potential appears to be due to a potassium diffusion and a non-passive distribution of chloride, leaving an equilibrium potential more positive than the potassium potential, (Gillespie, 1969).

Basic Electrical Rhythm.

Synonyms: Slow wave

Pacesetter Potential

Control activity

The intestinal smooth muscle, of all mammals studied so far, exhibits rhythmic variation of the membrane potential. This is the Basic

Electrical Rhythm (BER) or slow wave. The frequency of the slow wave is low, 3 - 20 cycles per minute (cpm) (0.05-0.33 Hertz) depending on the site in the gastrointestinal tract and the species.

Ionic Basis to the Basic Electrical Rhythm.

The variation in membrane potential is due to small (2-5 mV) cyclical changes in influx and efflux of ions across the membrane, (Job, 1969, cat small intestine). At the start of the cycle, i.e. from the resting potential, sodium ions flow into the cell and potassium ions flow out, down their concentration gradients. The membrane potential decreases from -50 mV until the sodium ions are pumped out and the cycle is reversed. In contrast, spike potentials are associated with rapid and much greater depolarization of the membrane. The sodium pump is metabolically driven and consumes energy, (Job, 1969).

Myogenic origin of spontaneous Electrical Activity.

Even though slow waves may be detected from smooth muscle strips in vitro, it is conceivable that neural remnants may continue to exert an effect on the smooth muscle membrane. Tetrodotoxin, from the Japanese Puffa fish, blocks sodium conduction across the axon, and neither Tetrodotoxin nor Procaine affect the slow wave frequency or amplitude in the cat, (Caprilli & Onori, 1972) although the amplitude is reduced in human colonic muscle in vitro, (Duthie & Kirk, 1978).

Rhythmic electrical activity may be detected from smooth muscle in the nerve-free chick amnion, (Prosser & Rafferty, 1956) and the origin of

the cyclical activity lies in the muscle itself and the cell membrane in particular.

Origin of BER in Muscle Layers.

In the cat small intestine, the BER originates in the longitudinal muscle layer and spreads into the circular layer, (Bortoff, 1965). By contrast, in the cat colon, the BER originates in the circular muscle layer, (Caprilli & Onori, 1972). This paradoxical situation does not appear to hold in most other species and in Man the colonic BER originates in the longitudinal muscle, (Vanasin et al 1971).

Electrotonic Spread of the Slow Wave.

Studies of small intestinal muscle (Bortoff, 1965), and colonic muscle in the cat, (Caprilli & Onori, 1972), have shown that the electrical slow wave, originating in one layer, spreads to the adjacent layer electrotonically. This is apparent by observing the synchronised exponential spatial decrement of slow waves which is characteristic of electrotonic spread.

Cable / Coupled Oscillator Theories

a). Cable Theory. The electrical activity of the smooth muscle cells has been compared with the physical properties of an electrical cable. The cells have a low resistance core, the cytoplasm, and a relatively high resistance outer membrane. The nexus provides contact between cells and electrical activity is transmitted from one area to another. The cable theory sugessts that the electrical slow wave rhythm

originates in one site, as the pacemaker of the heart does, and from there it spreads to surrounding smooth muscle fibres. However, multiple transections of the small bowel successively reduces the frequency of the slow wave in each segment which remains spontaneously active. This frequency gradient extends from the highest frequency in the duodenum to the lowest in the ileum. The Cable Theory has been superceded by the Coupled Oscillator theory which is more comprehensive.

b). Coupled Oscillator Theory.

Visceral smooth muscle fibres have inherent electrical rhythmicity in vitro, but as a rule, the frequency of the slow wave is less than that of the same fibres in vivo. This suggests that muscle bundles in vivo are being influenced to increase their frequency. The coupled oscillator theory holds that groups or bundles of smooth muscle fibres act as pacemakers and the pacemaker with the most rapid rhythm has the governing influence over its neighbours. The electrical activity may be propagated orally or aborally and each group of muscle bundles acting as a pacemaker or 'oscillator' influences neighbouring oscillators by coupling with them. If the chain of oscillators is broken by sectioning the bowel, the oscillators distal to the transection revert to a lower frequency suggesting that proximal influences were driving them, (Christensen et al, 1972, Diamant et al, 1973).

A mathematical model has been constructed electronically to simulate the output from numberous oscillators whose inherent frequency differs by small amounts, (Sarna et al, 1971, Linkens, 1976). This model is able to replicate features detected in myoelectrical recordings and has found most favour in current concepts of electro-physiology.

Slow Wave Frequency Gradient.

Diamant and Bortoff, 1969, measured the slow wave frequency of the small intestine in the cat, dog and rhesus monkey, at muliple sites along its length. In vivo, successive segments aborally had decreasing freguencies of slow wave. The slow wave frequency remained constant over plateaux of variable length. At the junction of the plateaux, waxing and waning occurred, which was thought to be the limit of influence of two loosely coupled oscillators, the higher frequency being unable to drive the lower frequency oscillator at this point.
The frequency plateaux and frequency gradient of the electrical slow wave may have a physiological effect by acting as a brake to motor activity, separating the intestine into individual motor segments.

Spike Potentials.

Synonyms: Action potentials

Spike burst

Fast activity

Response activity

Spike potentials are rapid depolarizations (50 milliseconds Bulbring, 1962) of the membrane potential and are usually seen on the peaks of the slow wave. Initial recordings were performed on the guinea pig taenia coli where Bortoff, 1961, described the reason for spike potentials being on the peaks of the slow wave i.e. where the membrane has been depolarized. Bortoff suggested that where the membrane potential becomes sufficiently depolarized, spike potentials are initiated and

this point is called the "spike zone". If the membrane potential is hyperpolarized i.e. remains below the spike zone then no spike potentials will be induced. In contrast, where the membrane potential is depolarized and crosses the spike zone, one or more spike potentials are initiated, (Figure 2). Not all species conform to this pattern. The rabbit, for example, has intermittent periods of continuous spike burst activity occurring over several slow wave cycles. It is possible that the complete slow wave has crossed the spike zone during these periods of spike activity or the spike potential threshold has decreased to include the full slow wave cycle.

Ionic Basis of the Spike Potential.

Whereas slow waves have been shown to be due to fluxes in sodium across the smooth muscle cell membrane, in contrast the spike potentials occur when rapid calcium influx takes place (Job 1969).

Relationship of Spike Potentials to Contraction.

Bozler (1938; 1946), recognised that spike potentials in smooth muscle were intimately related to contraction although not every contraction had a spike potential in relation to it.

The strength of contraction is proportional to the number of spike potentials (Bass & Wiley, 1965).

Factors influencing the Myoelectrical Activity.

The control of smooth muscle motor activity by nerves, stretch,

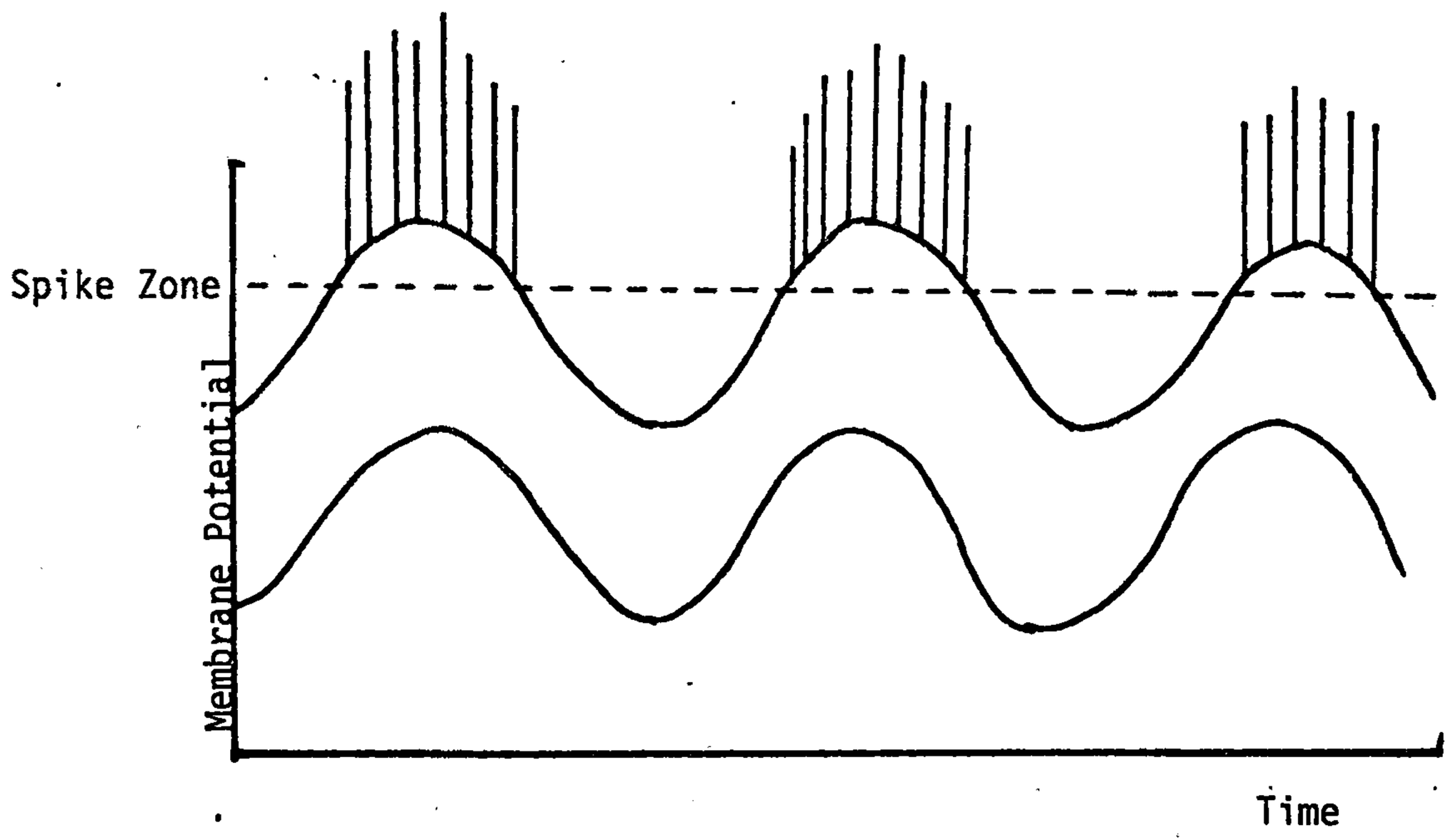


Figure 2. Diagram of Electrical Activity of the Small Intestinal Smooth Muscle.

In the upper trace the membrane potential enters the spike zone, thereby initiating spike potentials. Consequently, each slow wave is associated with a contraction.

In the lower trace the slow fluctuations of membrane potential do not enter the spike zone and despite the same amplitude of the slow wave, no spike potentials are initiated and consequently no contractions occur.

(Reproduced from Bortoff, A.
Intestinal Motility.
New England Journal of Medicine, 1969, 280,
1335-1337).

temperature and hormones is largely by modulation of the resting membrane potential, (Burnstock et al, 1963). Essentially, factors which depolarize the membrane lead to increased excitability, increased frequency of spike discharge and therby increased contraction. By contrast, factors which hyperpolarise the membrane lead to reduced excitability, a decrease or cessation of spike discharge and consequently relaxation. Figure 3 represents this diagrammatically.

Stretch.

The response to stretch of many different types of smooth muscle depends on the initial length of the muscle and/or the tension applied to it. Most smooth muscles are stimulated by moderate stretch which causes depolarization of the membrane, an increase in spike potential activity and a contraction or increase in tone (Bozler 1947).

Autonomic nerves.

The overall effect of stimulating one or other component of the Autonomic Nervous System depends on the state of the smooth muscle, (Bayliss and Starling 1899). In the cat small intestine, which is actively contracting, sympathetic stimulation results in membrane hyperpolarization and relaxation of the smooth muscle. By contrast, if the muscle is inactive, then stimulation by the same nerves results in membrane depolarization, spike potentials and initiation of contraction. Similarly, parasympathetic stimulation may result in inhibition rather than stimulation of contraction (Burnstock, Holman and Prosser 1963).

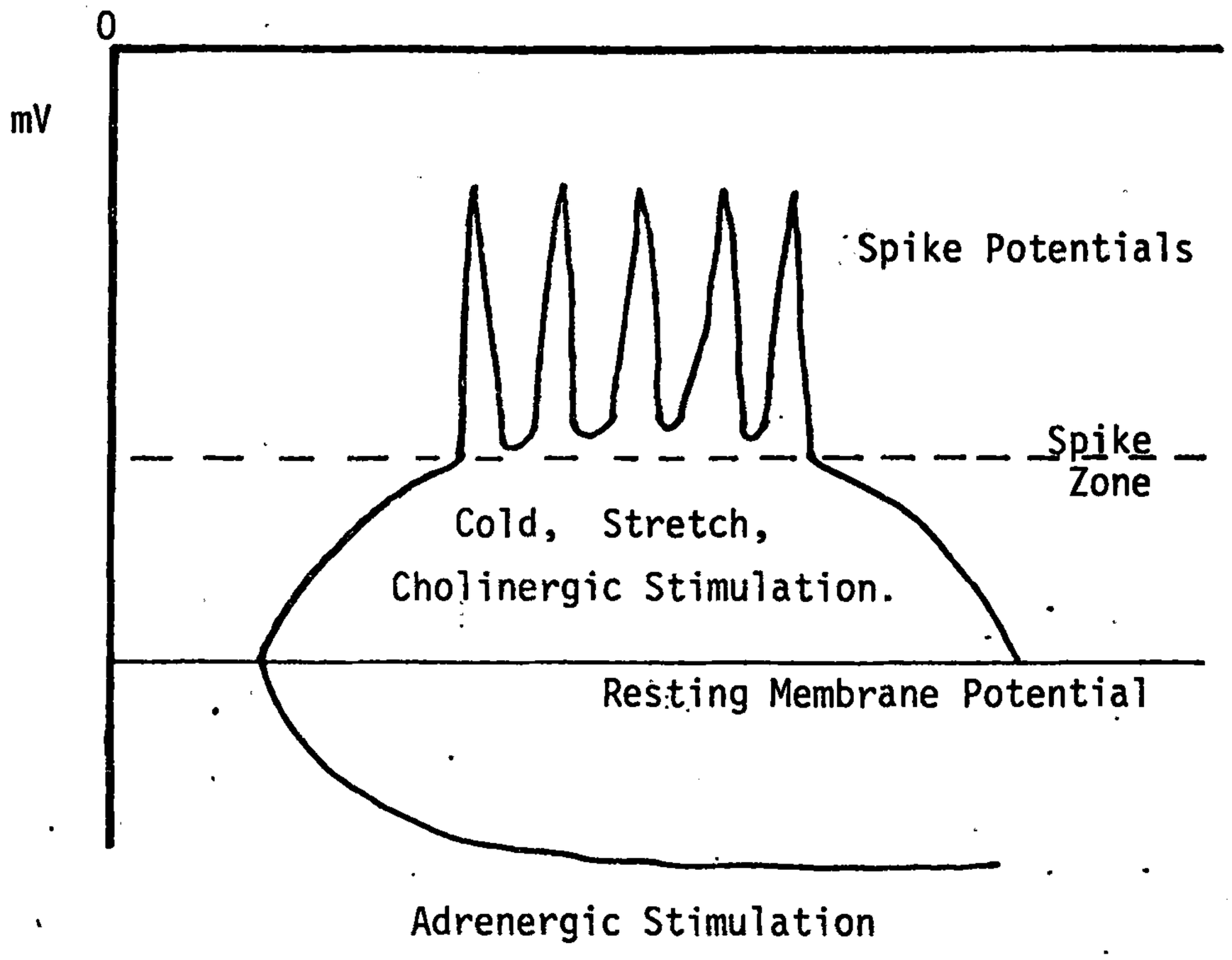


Figure 3. Representation of effects of regulating agents on membrane potentials of intestinal smooth muscle.

Cold, stretch or cholinergic stimulation depolarize the resting membrane potential into the Spike Zone with the consequent initiation of contractions.

Adrenergic stimulation hyperpolarizes the membrane taking it further away from the Spike Zone.

(Reproduced from: Burnstock, G, Holman, M.E., Prosser, C.L. Gastroenterology, 1963, 43, 482-527. Electrophysiology of Smooth Muscle.

Neurotransmitters.

Acetylcholine (Ach) increases the excitability of smooth muscle by membrane depolarization, increases in spike potential discharge and consequently increasing contraction (Bulbring 1962).

Adrenaline relaxes smooth muscle. Excitability is reduced, membrane potential increased and spike potentials inhibited. (Bulbring 1962). Although this basic generalization holds true, its action varies with type and species. Excitability of smooth muscle depends on the level of the resting potential. However, this is not the sole factor since spike activity is abolished before the membrane becomes hyperpolarized. (Burnstock 1963).

Noradrenaline and Isoprenaline have the same qualitative effects on smooth muscle as that of adrenaline.

Neostigmine and Physostigmine have similar actions to Acetylcholine on the intestinal smooth muscle.

5 Hydroxytryptamine (5HT). Taenia coli is very sensitive to 5HT, responding with contraction. The response is slow and a peak response is seen at 5 x 10-8 g/ml. (Burnstock 1963). At greater concentrations the spike discharge rate is reduced.

Prostaglandins of the F series (PGF) stimulate contraction in both muscle layers whereas the E series (PGE) contract longitudinal but relax circular muscle. (Vanasin et al, 1970).

Summary.

The smooth muscle of the gastrointestinal tract of all mammals studied so far, has revealed a rhythmic fluctuation of the cell membrane potential. The membrane potential (resting) is in the order of -50 to -70mV and is achieved by maintaining a concentration gradient of Sodium ions (Na+), the higher concentration existing in the extracellular fluid. During the depolarization phase of the slow wave, the cell membrane becomes permeable to Na+ which influx into the cell. This process is passive and does not appear to require energy. In contrast, repolarization of the cell membrane requires energy from oxidative phosphorylation in order to pump the Na+ out of the cell. As the depolarizing slow wave enters the "Spike Zone" spike potentials may be produced due to the rapid influx of Calcium ions (Ca++). Spike potentials initiate contractions and the greater the number of spike potentials the greater the strength of contraction.

The control of the spike potentials and hence the contractions lies in the fluctuating membrane potential i.e. the slow wave frequency, but, by depolarization of the membrane potential, the spike potentials increase and with it the strength of contraction. Conversely, hyperpolarization of the membrane removes the slow wave from the spike zone and inhibits spike potentials resulting in relaxation of the muscle.

ELECTRICAL ACTIVITY OF THE COLON IN MAN.

Slow Wave Frequency.

The colonic slow wave frequency, in vitro, has been recorded as 22±5cpm (Duthie and Kirk 1978) from muscle strips obtained at operation. Vanasin et al, 1971, showed a variation in frequency depending on the origin of the taenia muscle strips and demonstrated two frequency gradients: one from proximal transverse colon to caecum and the other from the distal transverse colon to the rectum corresponding to the proximal and distal colon respectively.

Table 2. Myoelectrical Activity in vitro.

	Frequency in cpm
Caecum	18.4
Proximal transverse colon	17.2
Distal transverse colon	18.2
Rectum	24.5

In vivo a different picture emerges.

1) There are two separate frequencies of slow wave (Taylor et al, 1974; Snape et al, 1976; Sarna et al, 1980).

2) These frequencies are considerably lower than those recorded in vitro. (Table 3).

Table 3. Myoelectrical Activity in vivo.

Frequency of Slow Wave in cpm

Reference	Duthie 1974	Sarna 1980	Taylor 1974	Snape 1976
Proximal colon	3+10	4.2 10.7		
Distal colon	3+7	4.6 10.7		
Sigmoid colon		4.0 10.3		
Rectum	3+6		2.5-4.0+ 6-9	2.9+7.3

Three theories have been proposed to explain the differences in slow wave electrical activity in vivo and in vitro:

1) Kirk, 1976, suggested that one frequency originated in the longitudinal layer and the lower frequency in the circular layer. If this were true it would explain why a single frequency was obtained from strips of taenia in vitro whereas two frequencies were obtained from the intact bowel in vivo.

However, previous in vitro studies, in animals and in man, show the origin of the slow wave activity to be in one or other layer and usually the longitudinal layer (Bortoff, 1965; Vanasin et al, 1971). Separation of the muscle layers results in an abscence of slow wave activity in the non-dominant layer (Bortoff, 1965). Kirk suggests that spike bursts at 2 - 10 cpm recorded from circular muscle in vitro may be interpreted as slow waves by the much larger, extracellular electrodes employed in

in vivo. This conclusion ignores the observation above that the circular muscle is "driven" by the longitudinal layer, electrically speaking, and observation of the gut in vivo shows that both layers contract together and in phase with one another (Bayliss and Starling, 1900).

2) Two separate frequencies of slow wave suggest two separate origins: either from the two muscle layers as discussed above, or from separate pacemakers or oscillators within the same dominant layer. Thus, one group of oscillators would have an intrinsic frequency in the low frequency range (3 cpm) and remain insensitive to the to the depolarising effects of the oscillators whose intrinsic frequency is in the higher frequency range (6-10 cpm). Taylor et al, 1974 and Snape et al, 1977 detected two frequencies of electrical slow wave from the human colon in vivo, 3 cpm and 6-9 cpm. The factors which govern switching on one group of oscillators in the low frequency range and switching off the other remains to be determined.

3) Recently, Chambers et al, 1981, detected a range of frequencies, 2-9 cpm, from human colonic smooth muscle in vitro. However, only one frequency was present at any one time, and other frequencies represented harmonics of the fundamental frequency. This finding in vitro may indicate a similar mechanism in vivo where more than one frequency has been detected simultaneously.

Bardakjian et al, 1976, recorded only a single frequency from the ascending colon in vivo which was present at all times. These recordings were obtained by electrodes implanted into the taenia at operation and the electrical rhythms were analysed by computer. It is possible that

both the method of sero-muscular electrode implantation rather than trans-mucosal implantation and the technique of computer signal analysis enabled a clearer detection of the colonic myoelectrical activity.

It is difficult to reconcile all reported findings and construct a single representative picture of the complex electrical activity of the human colon.It should be remembered that not only are technical details different between in vivo and in vitro animal recordings, e.g. electrode size and type, but in vivo human experiments require techniques which are as least invasive as possible. Taking ethical matters into consideration, many of the in vivo human recordings of electrical activity rely on the electrode(s) penetrating the mucosa in order to reach the muscle layer. The colonic mucosa has a significant electrical potential of its own, (Edmunds, 1975) which may produce an electrical frequency detected by the transmucosal electrode but not originating in the muscularis propria.

Another important factor when detecting electrical waves of such low frequency is the amplifier parameters. All recent published work employed amplifiers which were sufficiently sensitive. However, the Time Constants of the amplifiers varied to a great degree, (Taylor et al used 10 second Time Constant, whereas Snape et al used 0·45 seconds). The Time Constant is discussed in the Methods Section but, in summary, much of the low frequency component would be lost when a Time Constant less than 1 second is employed, approximately 38% of the signal below 9·5 cpm. The frequency content of the signal below 9·5 cpm is particularly relevant to myoelectrical recordings of the human colon.

Electrical Activity in the Irritable Bowel Syndrome.

The Irritable Bowel Syndrome (IBS) is discussed in greater detail in Section 2. Motility studies in this syndrome have progressed from intraluminal pressure studies, where increased sensitivity to stimulation has been described, to studies in the myoelectrical activity of the colonic smooth muscle. Having detected pressure wave or motor abnormalities in the IBS the question then arose as to whether there was an electrical abnormality at the root of this.

Slow Wave Frequency.

The timing of the spike potentials, and by inference the contractions, rests with the frequency of the BER or slow wave. Slow waves at 3 cpm frequency were associated with intraluminal pressure waves at the same rate. Snape et al, 1976, showed that the duration of 3 cpm electrical activity was significantly greater in the IBS group when compared with controls. In response to cholecystokinin or gastrin, the 3 cpm electrical slow wave increased in duration significantly more in the IBS and this was accompanied by motor activity at the same rate, (Snape et al, 1977).

Taylor et al, 1978, (b), compared an IBS group with a control group whose symptoms matched those of the IBS patients. This control group was chosen, rather than asymptomatic normals, in order to show that the greater amount of 3 cpm electrical activity was an inherent abnormality in the IBS rather than a result of the functional state of the bowel. They concluded:

> "the abnormally high incidence of 3 cpm electrical activity in the colon is specific to the IBS and not

merely a feature of the altered bowel habit."

This significantly higher incidence of 3 cpm was detected in the IBS both in relapses and remissions and Taylor, 1978 (a) concludes that there is a fixed electrical abnormality in this condition.

It is worth noting that these electrical studies were performed with electrodes inserted into the colon wall through the mucosa and required a sigmoidoscopy for their insertion .

Recordings with skin electrodes.

Electrical recordings from skin electrodes overlying internal organs, such as the heart and brain, have become common place and routine in hospitals throughout the world. The heart produces a relatively high voltage, related to the bulk of muscle. In contrast, intestinal smooth muscle has proportionately less volume of muscle and consequently a smaller voltage.

In view of our recent understanding of smooth muscle electrophysiology, it is surprising that as early as 1922 Alvarez recorded electrical potentials from the epigastrium of a very thin elderly patient whose stomach could be seen contracting through her abdominal wall. Davis et al, 1957, used a milliammeter and confirmed Alvarez' findings of a 3 cpm electrical wave detected from electrodes placed on the skin of the epigastrium. However their recordings were hampered by the use of a Direct Current (DC) amplifier. Sobakin et al, 1962, employing a more sensitive amplifier system were able to detect skin potentials in thin and obese patients and described "electrogastrographic" features in

epigastrium. However their recordings were hampered by the use of a Direct Current (DC) amplifier. Sobakin et al, 1962, employing a more sensitive amplifier system were able to detect skin potentials in thin and obese patients and described "electrogastrographic" features in various disease states: duodenal ulcer, pyloric stenosis and carcinoma of the stomach.

Martin et al, 1969, 1971, 1972 stressed the importance of a long Time Constant (3 to 6 seconds) in the amplifier to ensure a high fidelity response at low frequencies. Skin potentials were measured from electrodes on all four limbs and on the abdominal surface. 3 cpm activity was attributed to the antrum and 8 - 10 cpm activity to the small bowel. Supporting evidence for this came from Brown et al, 1975 and Drieux et al, 1977.

Sophisticated analytical techniques have been devised to separate accompanied noise from the signal frequency. Nelsen, 1967 and Smallwood, 1978 described phaselock techniques to extract the antral electrical activity and Brown et al, 1975, used Fourier analysis in order to display the frequency components graphically. Tonkovic et al, 1975, applied "spectral analysis" utilising a Fourier transform algorhythm when analysing their abdominal skin electrical activity. Linkens and Datardina, 1978, employed an autoregressive modelling technique on short sections of recorded electrical signals from antrum and colon in order to extract the bioelectrical frequency.

Correlation of Skin Potentials with Gastrointestinal electrical events.

Duthie, 1975, compared electrodes placed on the abdominal skin overlying

wave also had the same rate.

The origin of these skin potentials has been discussed most lucidly by Brown et al, 1975 listing four possible sources:

a) the signals were an electrode artefact

b) the 3 cpm electrical activity does not arise from the stomach but some other 3 cpm oscillator

c) the signals were a result of mechanical artefacts from the gut

d) the potential changes arise from the BER of the stomach.

a) was discounted by recording from electrodes at other sites, such as the arm, and being unable to detect waveforms.

b) Sources such as respiratory and/or skeletal muscle movement were discounted due to the difference in the frequency. The colon was considered a possible site for this 3 cpm activity but it was thought less likely as colonic electrical activity has been reported as being present only 5% of recorded time whereas the skin electrodes recorded 3 cpm activity for up to 88% of recorded time.

c) Motor activity of the stomach was associated with the BER in a 1:1 relationship but motor activity was not present all the time (Monges et al, 1969).

This reference relates spike potential activity to pressure increases rather than the BER itself. It should also be appreciated that motor activity may exist without detected change in intraluminal pressure. Brown goes on to say that the BER amplitude increases by 150% after a meal and that this is not due to increased mechanical activity but to the distended stomach lying closer to the electrodes.

d) Evidence for the stomach smooth muscle BER being the source

of the skin potentials, it is claimed, lies in the cross correlation of signals obtained synchronously from skin electrodes and intraluminal electrodes, which showed a good correlation. In addition, electrical activity may be recorded in the absence of mechanical activity as judged by intraluminal pressure measurements.

Certain criticisms may be levied at the conclusions detailed above:

1) Absence of intraluminal pressure waves does not equate with absent mechanical activity. The stomach may be contracting in one area and dilating in another resulting in no change in intraluminal pressure. On these occasions both electrical and motor activity would be present, and skin potentials recorded in the absence of intraluminal pressure activity do not necessarily indicate that the skin electrodes measured a purely electrical event.

2) After a meal the skin electrical potential amplitude increased by 150%. Brown suggests that this could be due to the distended stomach lying closer to the abdominal wall and the skin electrodes, suggesting that the proximity of the stomach muscle to the electrodes enabled a greater amount of the electrical energy to be detected. Smout et al, 1980, showed that the skin potentials correlated with the summation of the slow waves and the spike potentials. Smout's interpretation of this data was that it was not the proximity of the stomach to the electrodes which increased the amplitude of the signals detected by the skin electrodes, but the distended and thereby stimulated stomach had increased its spike potential discharge and the summation of the spike potentials and the slow wave peaks was transmitted to the skin and an increase in electrical activity thereby detected. It should be emphasised that Smout et al implanted strain gauges onto the serosal surface of the antrum and demonstrated that

this increase in electrical activity, slow waves plus the spike potentials, resulted in increased motor activity and it is possible that the movement of the stomach by these contractions may be of prime importance in the genesis of the electrical waves detected by the skin electrodes. This point will be argued in the animal experiment section.

SUMMARY.

Two distinct frequencies of slow wave have been described in the colon smooth muscle and the lower frequency, 3 cpm, is present more predominantly in the Irritable Bowel Syndrome.

Many investigators have used skin electrodes on abdominal skin to detect the gastrointestinal electrical activity and validation studies have attempted to show that skin electrodes were able to detect events which correlate with electrical and motor activity of the gastrointestinal smooth muscle.

Being a non-invasive, atraumatic technique, skin electrodes have been regarded with favour by both investigator and patient alike.

However, before subjecting a patient to a proposed study of skin electrical potentials it is most important to investigate the technique with particular emphasis on discriminating between motor and electrical events of the intestinal smooth muscle and their representation in the skin electrical potentials.

AIM.

1) Section 1 involves the evaluation of skin electrodes as a method for detecting intestinal smooth muscle electrical and/or motor activity.

GENERAL METHODS

Electrical Activity

The electrical potential or the change in potential is measured between two points. The arrangement may be unipolar where one electrode is in contact with the tissue under study and its pair is in contact with the body some distance away and with another tissue, often the skin. In contrast, where both electrodes of an electrode pair are inserted into the tissue under study the arrangement is said to be a bipolar one.

Metal electrodes in solution polarize or acquire a potential difference with respect to the solution. For electrophysiological purposes, the only requirement regarding polarization is that their difference for an electrode pair should be:

1) constant, or
2) small compared to the phenomenon under study.

By using electrodes of identical composition in a bipolar fashion it is possible to fulfil the above criteria. Whereas each electrode has a standing direct current (DC) potential, this is the same for each and theoretically no potential should exist between the two electrodes. Slight differences, such as metal impurities, may result in a small potential difference between the electrodes. Assuming this is constant then only changes in potential will be detected and amplified by an Alternating Current (AC) amplifier.

Insertion of the Electrode.

The electrodes used in vivo were all extracellular electrodes and were implanted into the muscle. Firm fixation was essential to obtain clear recordings free from artefact. Movement of the electrode at the site of insertion created transient potentials, often much greater than those being studied.

Amplifier.

Alternating Current (AC) amplifiers were chosen in preference to direct current (DC) amplifiers as they are unaffected by standing potentials and recorded changes in that potential. Extracellular electrodes tend to have relatively high electrode potentials e.g. 10 - 50 millivolts for stainless steel, but clean and stable recordings are possible with AC amplifiers.

Time Constant.

The low frequency response of an amplifier is determined by its Time Constant. This is particularly important when recording frequencies as low as 2 - 4 cpm. At these frequencies a long Time Constant is required:

$$fo = \frac{1}{2pi.tau}$$

where fo = the frequency at which a signal loss of approximately 30% (i.e. -3dB) occurs.

tau = Time Constant in seconds.

then where: tau = 1 second; fo = 0·16 Hz (9·5 cpm)

tau = 3 seconds; fo = 0·05 Hz (3·18 cpm)

tau = 5 seconds; fo = 0·03 Hz (1·19 cpm)

tau = 10 seconds; fo = 0·016 Hz (0·95 cpm).

Recent published works in myoelectrical activity concentrating on slow wave frequency rather than spike potential discharge, have shown a wide variation in Time Constant employed. Taylor et al used a 10 second Time Constant and Thillier and Bertrand used 6 seconds, whereas Snape et al used 0.45 seconds Time Constant. Obviously, much of the low frequency component of the signal will be lost unless a Time Constant of several seconds is employed.

METHODS EMPLOYED

Recording Instruments

Multichannel Pen Recorder

Recordings of electrical activity from implanted and skin electrodes, and of intraluminal pressure or strain gauge activity were made on heat sensitive paper driven by a Devices 6-channel recorder.

Separate plug-in modules were available to match the type of input, for example, EEG amplifiers for electrical recording, pressure modules for pressure and strain gauge recordings.

The paper speed was set at 50 millimetres per minute but was found to be 52 millimetres on testing the equipment.

Magnetic Tape Recorder

Recordings from four selected channels were made on 1/4 inch magnetic tape (Agfa PE 268) with a Frequency Modulated four channel tape recorder (Racal Store 4) (Figure 5). The recording speed was 15/16 inches per second.

The tape recorder had a wide frequency response and being frequency modulated, the low frequency response extended to zero.

Magnetic recordings allowed computer analysis at a later date.

Figure 4.

The Devices 6-track pen recorder containing the plug-in modules to measure electrical, pressure and strain gauge activity. These parameters were recorded on heat sensitive paper located in the lower half of the apparatus.

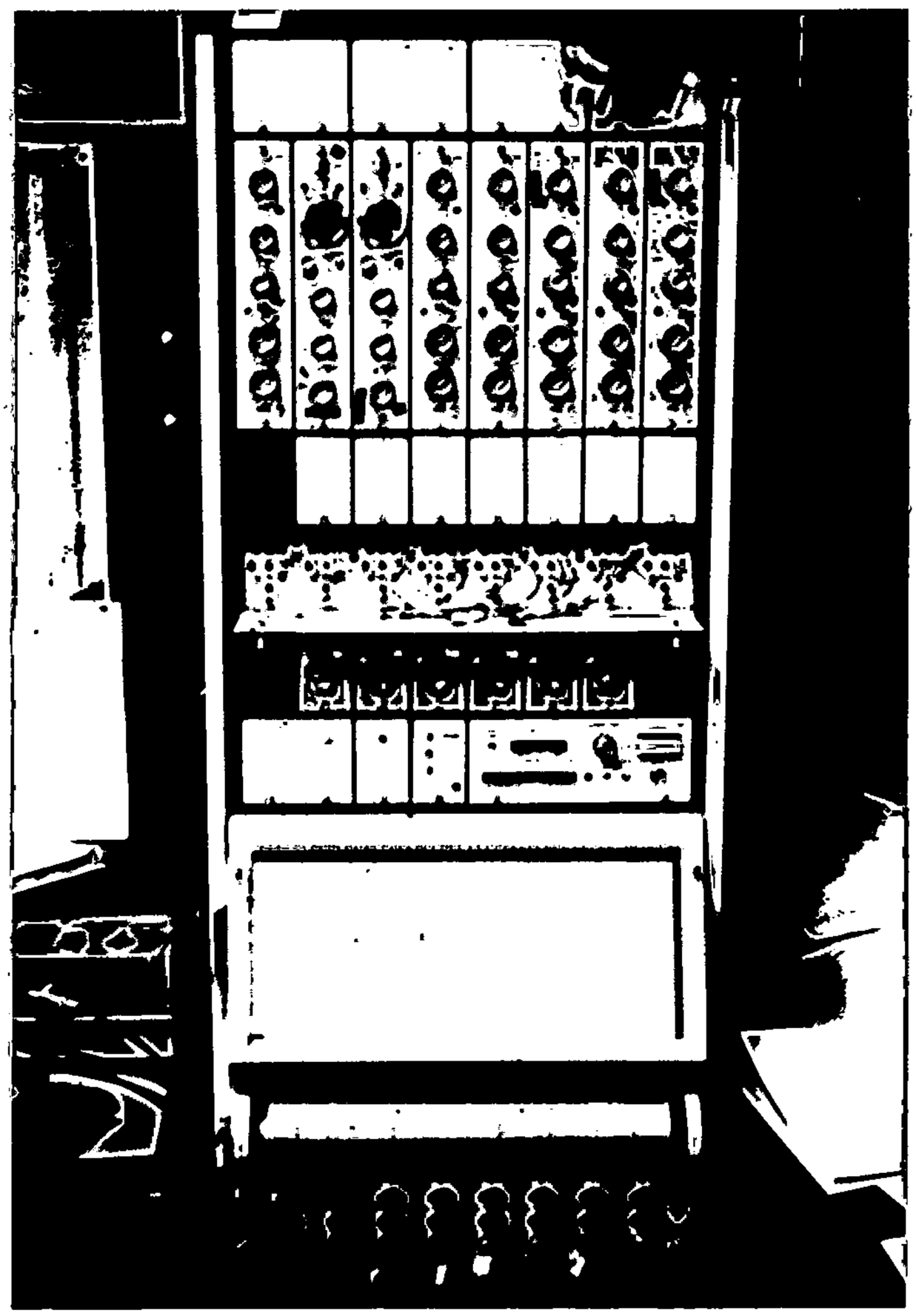
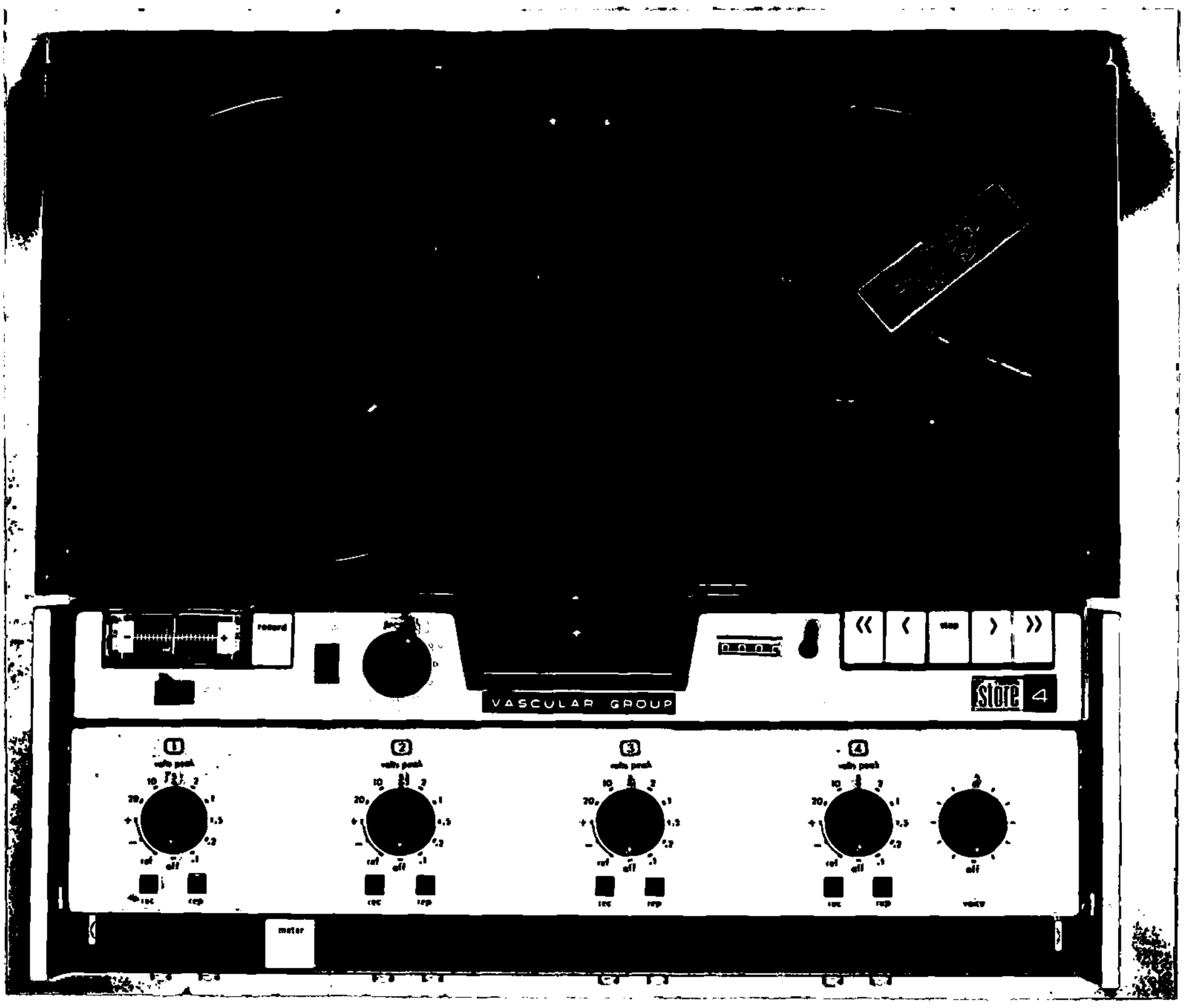


Figure 5.

The Racal Store 4 FM Tape Recorder.
This was a four track reel-to-reel tape recorder capable of recording extremely low frequencies and replaying them for computer analysis at a later date.



ELECTRICAL ACTIVITY

Amplifier Parameters

Standard Electroencephalogram (EEG) amplifiers were used. These were AC- coupled amplifiers with a Time Constant of 10 seconds.

Standardisation was set with each amplifier so that 1 millivolt = 15 millimetres or 15 small squares on the recording paper.

Electrical recordings were made in bipolar fashion and in addition, each channel incorporated an "earth" which was connected in common to the right thigh of the rabbit.

ELECTRODES

Three types of electrode were employed in detecting the intestinal myoelectrical activity.

Implanted electrodes

Composition

The implanted electrodes, used in the rabbit, were composed of 34 SWG stainless steel wire which were insulated in polytetrafluoroethylene (PTFE) sleeving (Figure 6).

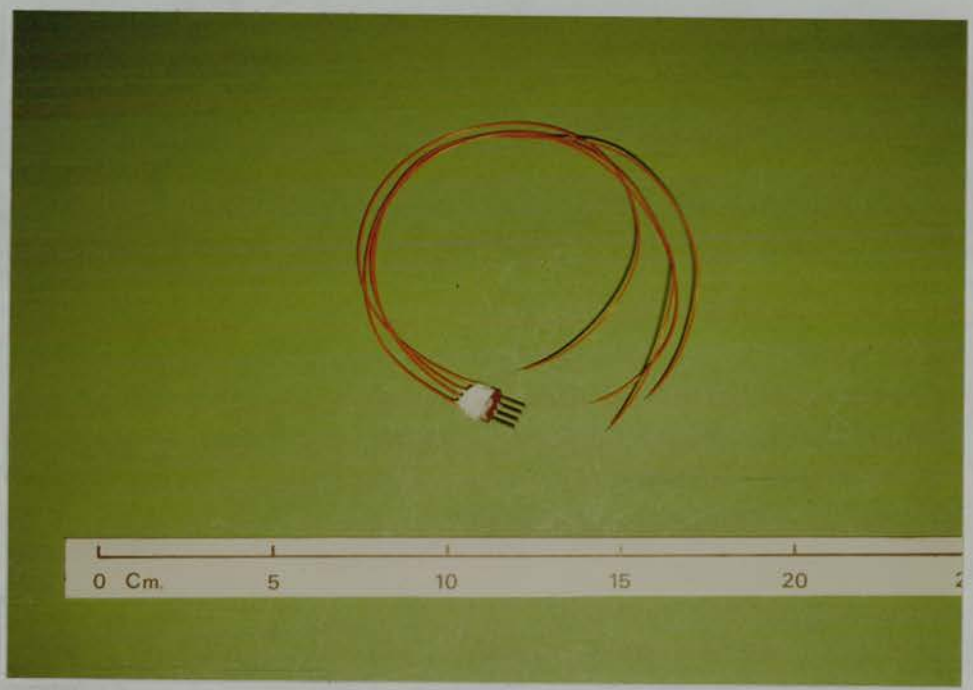


Figure 6

The stainless steel electrodes were implanted into the smooth muscle of the rabbit gastrointestinal tract. The stainless steel wire was sheathed in orange PTFE tubing and soldered to the 4 pin plug.

Construction

Two pairs of stainless steel wire electrodes, 22 centimetres in length, were soldered to the terminals of a 4-pin plug (Radiospares board plug) using stainless steel solder. PTFE sleeving was inserted over the length of the wire allowing two millimetres exposed for implantation. The PTFE sleeving was fixed in place and the soldered joints insulated by embedding the junction in silicone rubber (Evostick Colourseal).

Skin Electrodes

Type

Adhesive silver-silverchloride electrodes (Ormed ECG) were attached to the shaved skin of the abdomen of the rabbit (Figure 7). Cambridge Electrode Jelly was applied to the surface of the electrode to augment electrical contact between skin and electrode.

Sites of Attachment

The electrodes were situated in pairs for bipolar recordings. In addition, an electrode on the right thigh was earthed and common to all amplifiers.

The standard positions for the electrodes are shown in Figure 8. A transverse pair and a longitudinal pair on the abdomen were occasionally supplemented with an anteroposterior pair of electrodes.

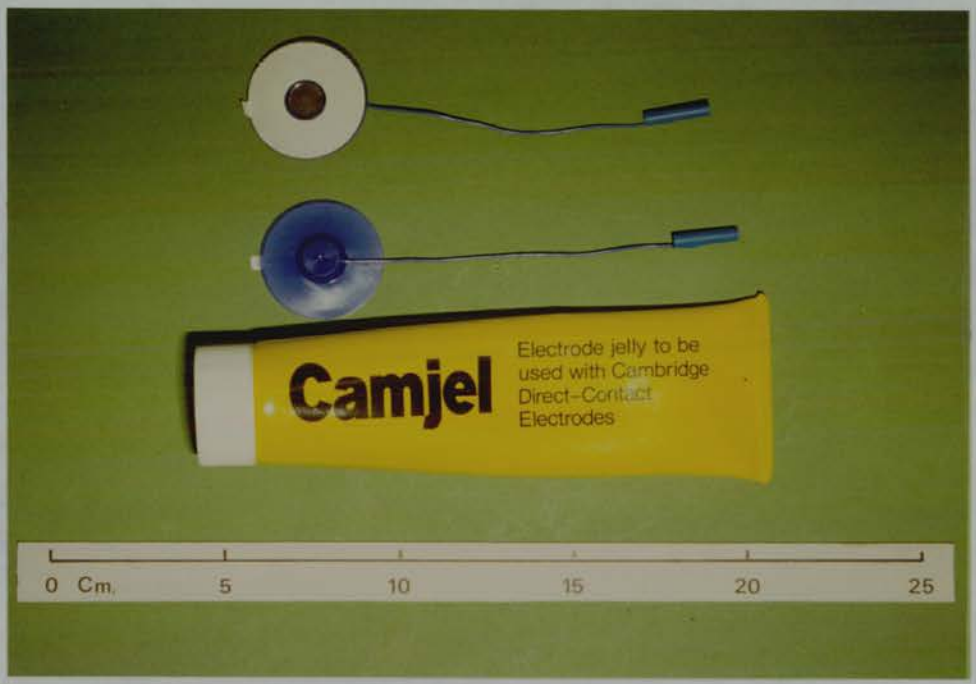


Figure 7

Ormed silver-silverchloride electrodes and the Electrode gel which was applied to the cup prior to exposing the adhesive surface and attaching to the shaved abdominal skin.

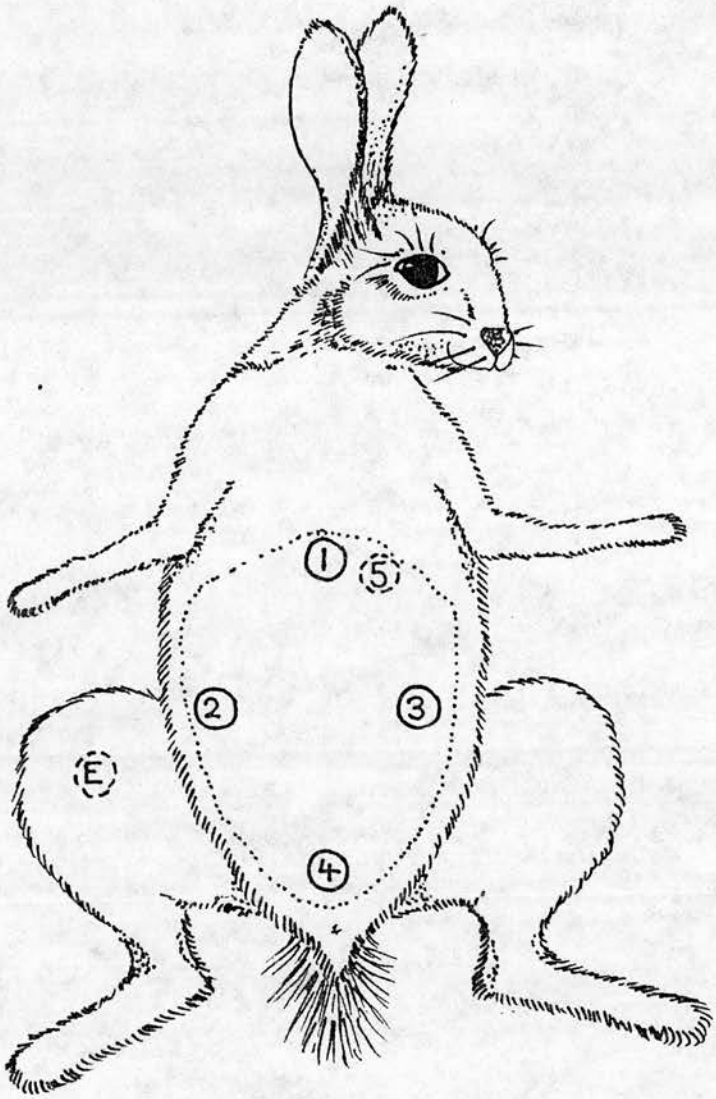


Figure 8. Diagram to illustrate the standard sites of skin electrode attachment. Bipolar recordings were made between 1-4; 2-3 and in addition, 5-4. (5 was situated on the dorsal thoraco-lumbar area). E was the Earth electrode connecting the rabbit, all recording channels and the amplifiers to earth.

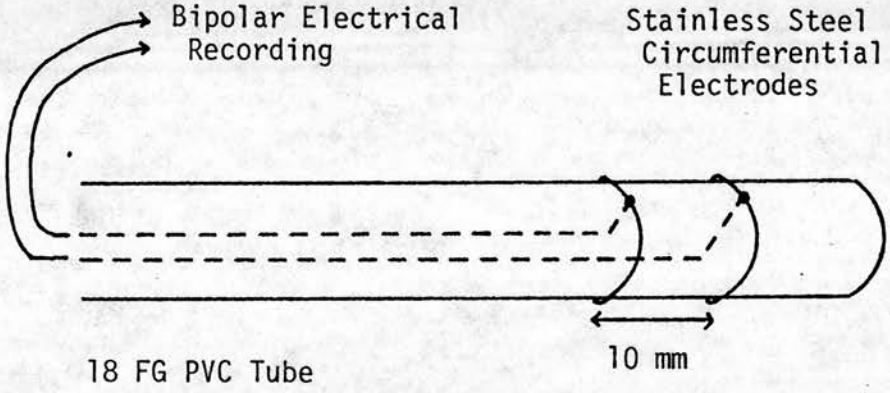


Figure 9. Diagram illustrating the Circumferential Electrodes mounted onto a PVC tube. This electrode probe was inserted into the rectum of the rabbit and electrical potentials were measured between the two electrodes.

Intraluminal Electrode Probe

Description

This electrode was designed to be inserted per rectum and detect the electrical activity of the smooth muscle from the contact of the electrode and the mucosa. This technique has since been described by Bueno et al, 1980.

Construction

The electrodes were composed of a loop of stainless steel wire, 34 SWG, placed around the circumference of an 18 FG Polyvinylchloride tube. Two circumferential loops were situated at the distal end of the PVC tube (Figure 9) and were 10 millimetres apart. Each loop was connected to a PVC covered copper wire which was situated inside the tube and transmitted potential changes to the Devices AC amplifiers.

Comment

This method was included as it has been employed by other investigators. No means of attachment to the bowel was used and contact with the mucosa was established through the mucus lining the bowel.

In use, the electrical activity took 30 minuted to settle to a rhythmical wave-like fluctuation. However, on removing the electrode probe, identical wave-like activity was reproduced by gently rubbing the lubricated finger across the electrodes.

This method most probably detects (contraction) movement artefact and there is no evidence that myoelectrical activity is being recorded.

The use of this method for recording smooth muscle electrical activity was abandoned.

MOTOR ACTIVITY IN THE RABBIT

Strain gauges

The motor activity of the colon was detected by strain gauges implanted transversly on to the serosa of the rabbit colon.

The strain gauges were designed to be bonded to steel structures in order to measure stress and strain. However, flexing the gauge on the polyester backing strip alternately compressed and stretched the strain gauge which was adherent to one surface. This compression and expansion changed the strain gauge resistance which was relayed as an imbalance on the Wheatstone circuit. In this manner, changes in the curvature of the bowel were measured and hence the contractions were identified.

Construction

Each strain gauge (RS 308-102 - Radio Spares) was 8 millimetres in length and mounted on a polyester backing strip (Figure 10). A PVC covered copper core wire was soldered to each terminal and the strain gauge and connections were encapsulated in silicone gel (Evostick Colourseal). The encapsulation was dumb-bell shaped which allowed fixation to the bowel by the insertion of a 4/0 silk suture at both ends of the strain gauge, (Figure 11).

Pressure Module

Each strain gauge was connected to a Devices pressure module through the same input socket that would be used for pressure measurements. The amplifier module used incorporated half a Wheatstone bridge as part of

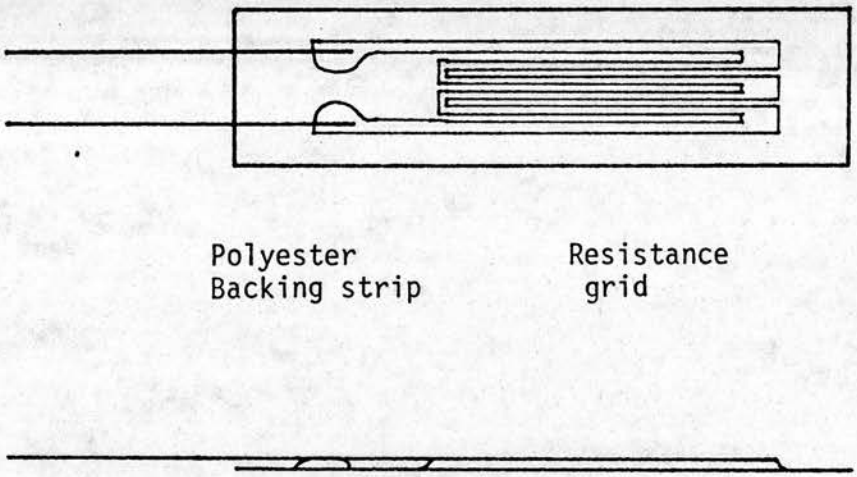


Figure 10. Diagram of the Strain Gauge employed in the strain gauge studies and in the Strain Gauge Probe.

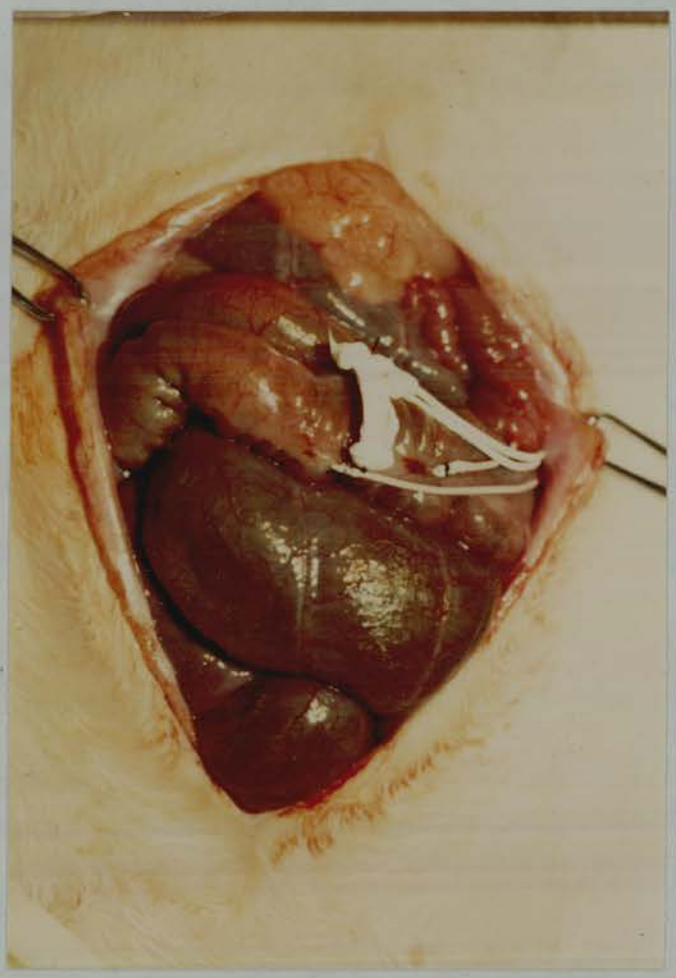


Figure 11

The encapsulated strain gauge was attached transversely to the colon by a 4/0 Silk suture at either end of the silicone rubber encapsulation. A pair of stainless steel electrodes have been implanted into the taenia on either side of the strain gauge.

its input circuitry. The strain gauge resistance (120 ohm), balanced by another 120 ohm resistor (R4), was used to complete the bridge. This resistor was incorporated in the plug connecting the recorder to the strain gauge, (Figure 12), and was insulated from changes in temperature by its encapsulation within the plug.

Circuit Diagram of the Wheatstone Bridge.

The Wheatstone bridge is described because the the conception of the "strain gauge probe" originated from an understanding of its circuitry. Figure 13 illustrates the basic Wheatstone Bridge. A pen recorder was substituted for the meter in the centre.

When $\frac{R1}{R2} = \frac{R4}{R3}$

then the potential difference across A - B = 0.

The meter reads zero.

When R1 = R2 but R3 < R4

then more current flows through R1 and R3 and a potential difference exists across A - B. The meter needle will swing accordingly.

Modification to the Circuit.

In the recording apparatus, R1 and R2 formed the half bridge within the pressure amplifier module. R3 represents the strain gauge resistance and R4 represents the 120 ohm resistor to balance the strain gauge (Figure 12).

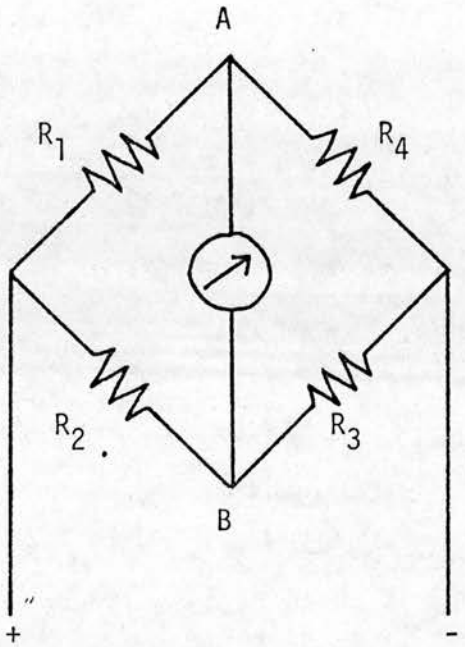


Figure 13.

Circuit diagram of the Wheatstone Bridge.

The bridge is balanced when there is zero potential across A-B, and $R_1 = R_2$; $R_3 = R_4$.

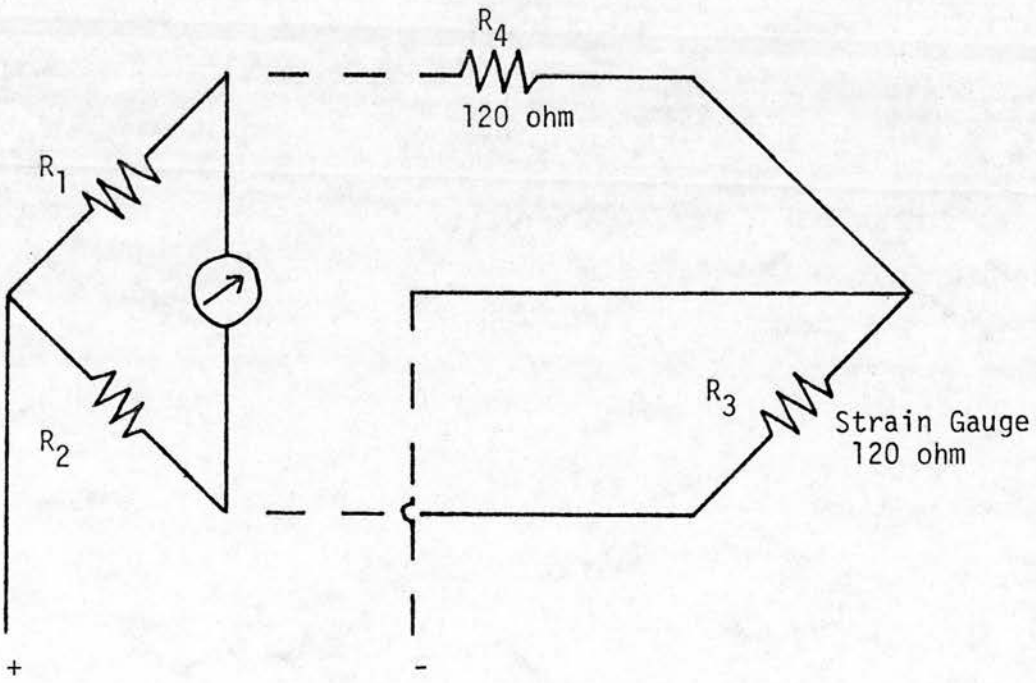
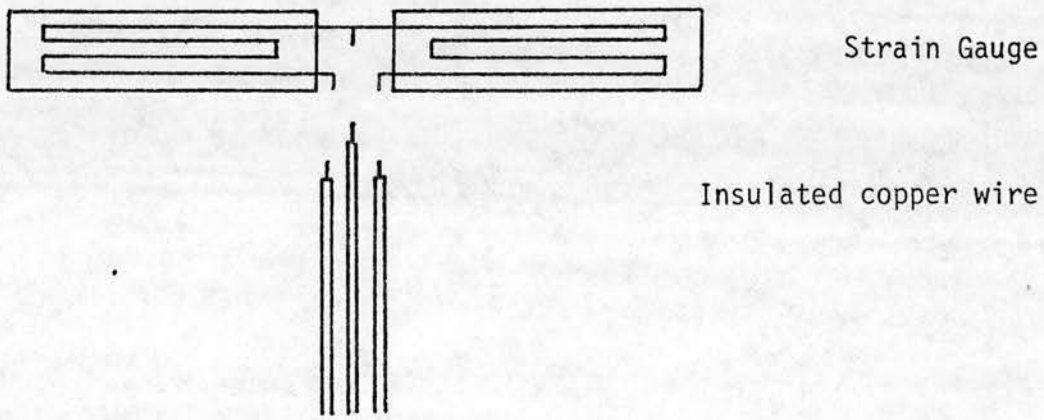


Figure 12. Circuit diagram of the Wheatstone Bridge incorporating the strain gauge implanted onto the rabbit colon.

The internal resistance of the strain gauge, 120 ohms, R_3, is balanced by a 120 ohm resistor in the lead to the amplifier, R_4.

Figure 14. Diagram to illustrate the electrical connections between the strain gauges and the insulated wire leads to the Wheatstone Bridge in the amplifier.



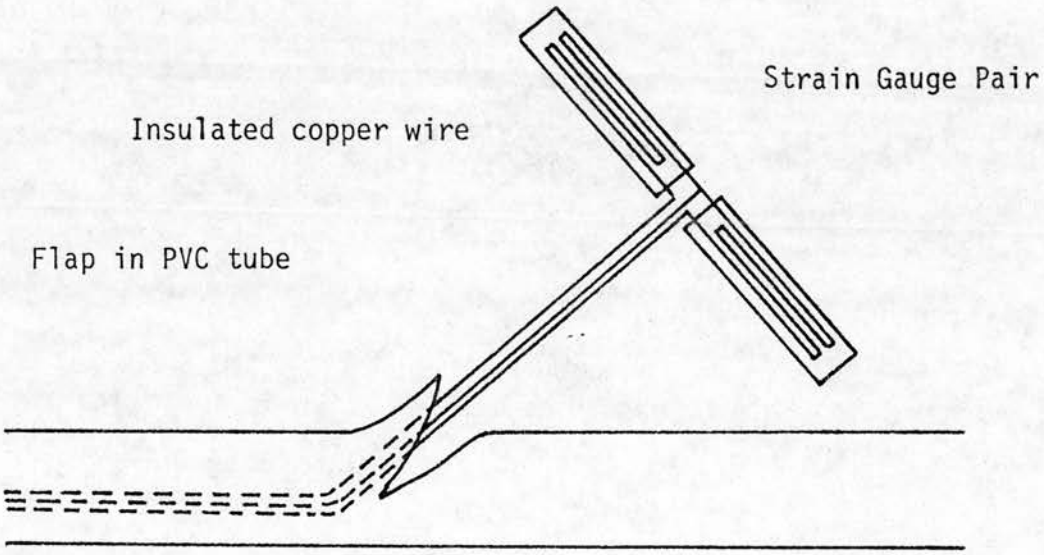


Figure 15. Diagram to show the strain gauge pair being drawn into position into the flap cut into the body of the PVC tube during construction of the Strain Gauge Probe.

MOTOR ACTIVITY IN MAN

Strain Gauge Probe

Description

The strain gauge probe was designed to detect contractions at three separate points 50 millimetres apart, together with intraluminal pressure at the tip of the probe. Strain gauges were chosen because they were not influenced by changes in intraluminal pressure and responded only to changes in curvature of the strain gauge "wings".

Construction

A PVC tube 60 centimetres in length and 8 millimetres in diameter, was adapted to support three strain gauge pairs and one perfused open ended tube. One end of the PVC tube, the sensory tip, was occluded with chips of PVC dissolved in cyclohexanone. This made an excellent PVC glue. Three oblique flaps in the side of the tube were cut at 1, 6 and 11 centimetres from the tip and three insulated copper wires were inserted through the tubing and out of each of the defects. Two millimetres of the copper were exposed and soldered to a pair of strain gauges, one of the wires being common to both, (Figure 14). The copper wires were drawn back through the tube carrying the strain gauges with them to the base of the incision in the PVC tube, (Figure 15). The defect was closed with PVC glue which sealed the soldered connections within the tube. The strain gauge pair were aligned like wings on the body of the PVC tube.

A hole was made in the PVC tube opposite and at the same level as the strain gauge pair at the tip of the probe. An 8 FG polyethylene tube was inserted through this hole and the junction sealed with PVC glue.

Any excess material was shaved off with a scalpel. The polythene tube was connected to a pressure transducer and perfused with water.

Once the PVC glue had cured, the PVC tube and strain gauge wings were cleaned with a degreasing solvent prior to coating with Silicone Rubber (ICI - SILICOSET). The silicone rubber insulated the strain gauges, protected their surface and maintained their flexibility.

Figure 16 illustrates the uncoated Strain Gauge Probe.

An important point in construction was the alignment of the strain gauge. In each pair, one was aligned face up and the other face down. In this configuration, flexion of both strain gauges compressed one resistance grid while expanding the other. In this manner, the imbalance of resistances was accentuated rather than counteracted.

Circuit Diagram

In the strain gauge probe, there were two strain gauges in each circuit, so a balancing resistor was not required. The strain gauge pair form half a Wheatstone bridge (Figure 17) and is identical to the circuit diagram of the strain gauges on the diaphragm of the pressure transducer.

A smooth muscle contraction, acting on the strain gauges, would increase their curvature and change the resistance of the strain gauges. Due to

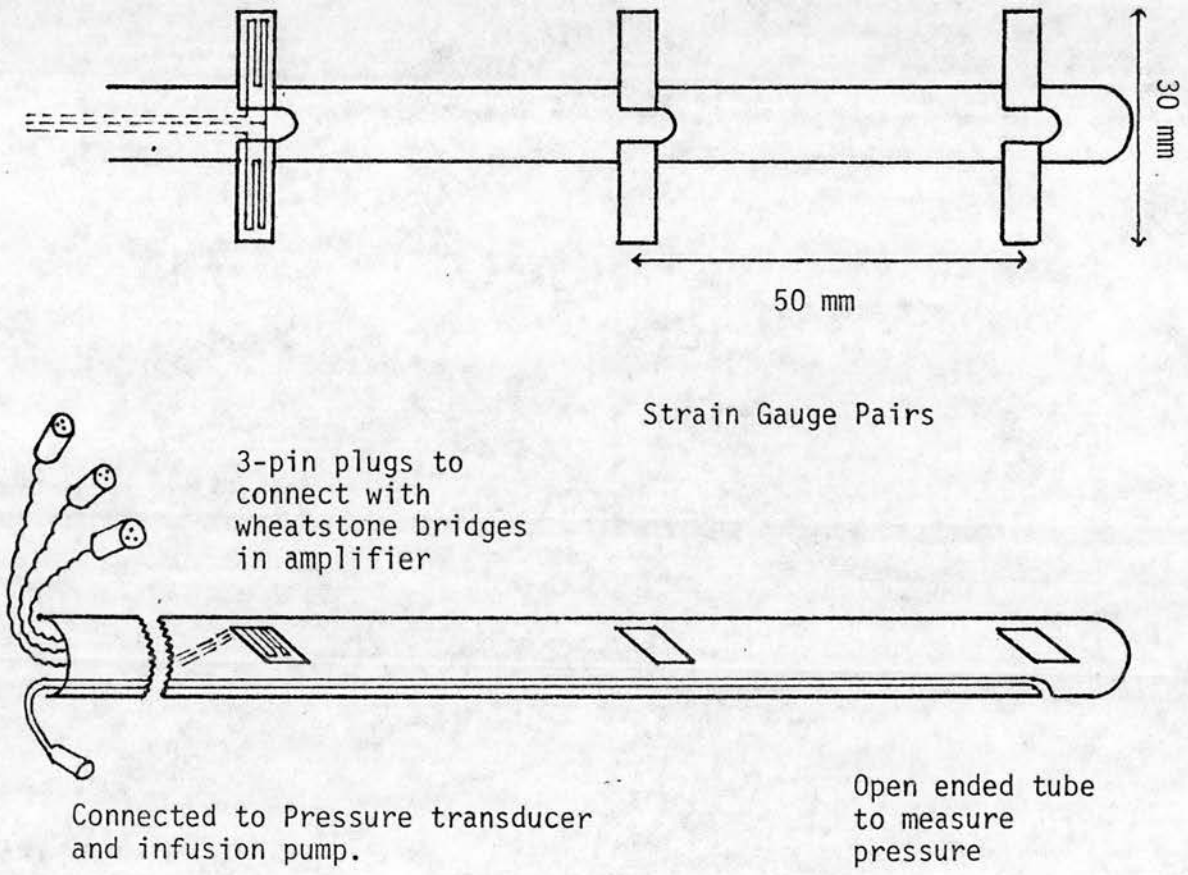


Figure 16. Diagram which illustrates the sensory tip of the Strain Gauge Probe. The strain gauge pairs were situated 50 mm apart with a perfused tube opening opposite the strain gauge pair at the tip. Contractions were detected at three levels along the probe, by the strain gauges, and intraluminal pressure was detected by the perfused tube. Changes in Tone were detected by the combination of the pressure and strain gauge recordings.

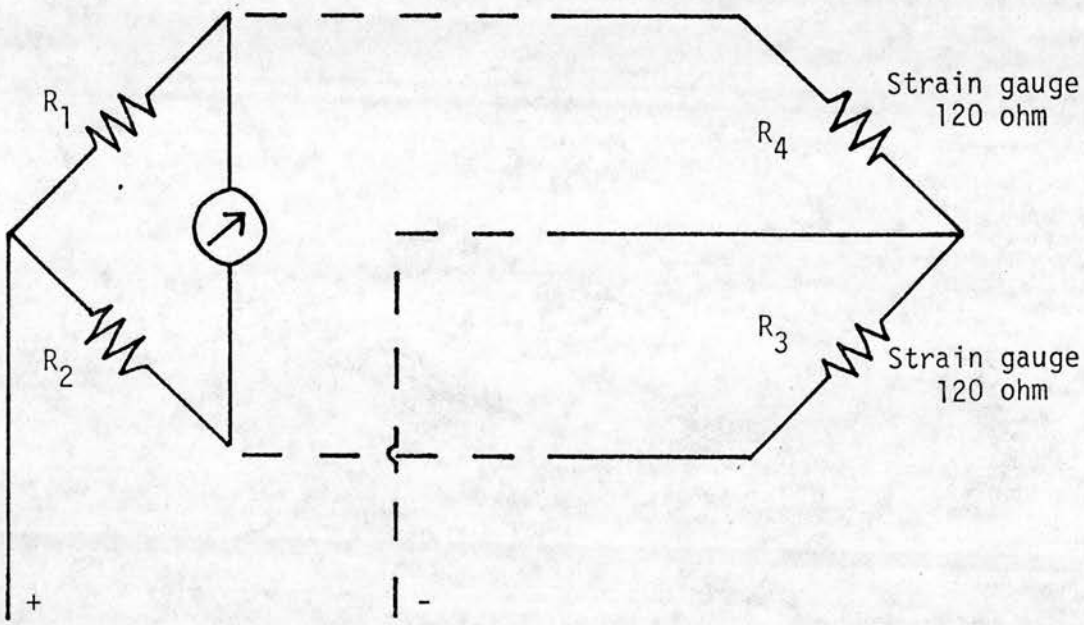


Figure 17. Circuit diagram of the Wheatstone Bridge incorporating the strain gauges in the Strain Gauge Probe.

The strain gauges, R_3 & R_4, were mounted on the probe and responded to changes in curvature of the bowel lumen. R_3 was mounted upside down so that the curvature of the strain gauges increased the resistance in one while decsreasing it in the other thereby accentuating the imbalance.

their alignment, the resistance in one strain gauge would increase while that in the other would decrease thereby accentuating the imbalance in the Wheatstone bridge.

Modification of Pressure Amplifier

The strain gauges were connected to the same amplifier module as the pressure transducer and required no modification to the primary circuits.

However, initial testing showed that the strain gauge surfaces heated up after 15 - 20 minutes of running. The energising voltage to power the circuit when recording pressure was six volts. The voltage was decreased to one volt in the modules connected to the strain gauges. Although this reduced the sensitivity, no increase in temperature of the strain gauges occurred. The decrease in sensitivity of the strain gauges at this voltage was adequately compensated by a higher sensitivity setting in the pressure amplifier.

Pressure Transducer

The open-ended tube in the Strain Gauge Probe was connected to the dome of an Elcomatic Pressure transducer, type EM - 750.

Calibration

Calibration was carried out in centimetres of water and a pressure of sixty centimetres of water resulted in a full scale deflection.

Once the recording apparatus had attained working temperature, the

baseline was zeroed with the open ended tip at the level of the centre of the pressure transducer diaphragm. The tip was raised ten centimetres against a vertical centimetre rule. Incremental steps of ten centimetres to a maximum of sixty centimetres gave a stepped calibration of pressure on the recording paper.

During recording, the transducer was positioned level with the couch on which the patient rested.

Infusion Pump

A Harvard infusion pump compressed a syringe of water which delivered a constant flow of water to the dome of the Elcomatic pressure transducer and to the open ended tube.

Rate of flow

The rate of flow was 0·28 millilitres per minute, (ml/min). Perfusion of the tube prevented the lumen from blocking with faeces. Various flow rates from 0·28 ml/min to 2·8 ml/min were employed in a bench test to detect any difference in accuracy or sensitivity but none was found within this range. Although the advantage of a high infusion rate prevents the orifice of the pressure tube from being occluded by the mucosa or faeces, it delivers a greater volume of water into the lumen of the colon which may induce spurious activity. The open end of the pressure line was situated in such a position that, with the probe inserted into the sigmoid colon and rectum, the surface of the probe opposite the pressure orifice was in contact with the bowel wall and the orifice was directed to the centre of the lumen of the bowel.

Animal experiments

Forty two New Zealand White rabbits, 2.5 - 4 kg of both sexes were chosen for this study. Rabbits proved to be a suitable model in which to study the effectiveness of different recording techniques; they have a colon which is sacculated containing taenia, like man but unlike cats and dogs. They were easy to handle, not too small to require different sized electrodes, relatively cheap to maintain and hardy enough to withstand the procedures to which they were subjected.

Anaesthesia

One hour before induction of anaesthesia 1 mg/Kg Droperidol was given by intramuscular injection. The rabbit was wrapped in a clean towel and placed on the lap with a face mask over the nose delivering oxygen/nitrous oxide gas in equal proportions and at four litres a minute supplemented with Halothane starting at 0·5% and increasing gradually to 3%. This was reduced to 2% after the peritoneum was opened and maintained at this level for the duration of the operation.

Intravenous fluid administration was necessary in a small number of animals where large resection of bowel was performed.

Operation

The abdominal skin, nape of the neck and two areas on lower chest posteriorly were shaved of fur. These areas were cleaned with Cetavlon in spirit and a 1 cm incision made in each of the shaved areas on the lower thorax. A 12 FG Medicut cannula and stilette were inserted subcutaneously through the incision to the base of the neck. The stilette was withdrawn and the electrodes were passed down the cannula to exit at the lower thoracic area. With electrode leads inserted on both sides the animal was turned on to its back and a 10 cm midline longitudinal incision made in its abdomen. The bowel was handled as little as possible. A gauze swab soaked in saline was placed over the loops of bowel which were retracted across to the midline revealing the posterior peritoneum and kidney. Under direct vision the 12 FG Medicut cannula and stilette were passed through the abdominal wall posteriorly, inferior to the costal margin and through the 1 cm incision in the skin, where the electrodes were situated. The stilette was removed and the elecrodes introduced to the peritoneum via the cannula.

Attachment of electrodes to seromuscular layer

2 mm of the stainless steel wire protruded from the PTFE sleeve. The implantation into the muscle layer was achieved by first passing a 21 FG green hypodermic needle through the muscle layer and out through the serosa for a distance of 4 - 6 mm. The bare electrode end was bent through 150° and inserted into the lumen of the hypodermic needle which was then withdrawn leaving the electrode implanted into the muscle. A 3/0 chromic catgut suture was inserted into the muscle layer away from the site of the implantation and tied around the PTFE sleeving, thereby

anchoring the electrode.

Other methods which proved less successful in diminishing order were:

a) Forming a loop in the electrode, the free end being inserted into the muscle layer and the electrode anchored by a 3/0 chromic catgut suture inserted through the adjacent seromuscular layer, the loop in the elecrode and another bite through the seromuscular layer. When tied, the suture buried the site of implantation. It was considered that local manipulation of muscle and tissue around the site of implantation might affect the electrical activity and this method was abandoned although the method of anchoring was effective.

b) The electrode was inserted unbent into the muscle layer via a 21 FG hypodermic needle and a 3/0 suture, in taking a bite on either side of the electrode invaginated the seromuscular layer over the electrode. This method was associated with a high incidence of dislodged electrodes.

Attachment of strain gauge to the seromuscular layer

The silicone rubber covered strain gauge was attached transversely to the axis of the colon by two 4/0 silk sutures inserted at both ends of the strain gauge, through the silicone rubber and into the antimesenteric taenia. Where electrodes were employed at the same time, they were inserted into one of the taenia on both sides of the strain gauge.

Closure of the abdomen was performed with 2 layers of continuous 2/0

Nylon and care was taken to bury the knots.

Recovery

The Nitrous oxide and Halothane were turned off and the rabbit was allowed to breath 100% oxygen for 5 - 10 minutes before being placed on an electrically heated pad for 20 minutes. The rabbit was allowed free access to food and water once it was returned to the cage. Notice was taken of oral fluid intake over the first 24 to 48 hours.

Recordings

If electrical recordings were taken in the first six hours after operation, they showed the presence of waveforms which were neither characteristic nor representative of the normal electrical activity seen after full recovery. For this reason recordings were commenced 48 hours after the operation and on successive days. A maximum of five recordings were taken over a period not exceeding ten days.

Sedation

10 mg intramuscular Diazepam was given to the rabbit under study one hour before starting recordings. Recordings with this moderate sedation prevented multiple movement artefacts, dislodging the skin electrodes and chewing of electrical connections. Food and water were witheld two hours before the recording period but fasting the rabbits was impractical due to their habit of coprophagia.

Attachment of skin electrodes

The skin was prepared by reshaving the abdomen and any sites requiring attachment of the skin electrodes. Electrode jelly was rubbed on to the skin over a 1 cm square area to match the silver-silver chloride skin electrode. Electrode jelly was applied to the electrode surface, enough to cover the electrode and flush with the adhesive layer. The protective paper was removed from the adhesive layer and the electrode pressed on to the prepared skin (Figure 18). When all the electrodes were attached the rabbit was placed in a restraining box which was open at the top and with an aperture in front (Figure 19). This served to discourage movement during the recording period. Once in the box, the leads to the recording machine were attached to the skin electrodes and to the 4 pin plug(s) at the base of the neck (Figure 19).

Basal and Stimulation Recordings.

Basal activity was recorded for sixty minutes. A further sixty minutes of recording followed the administration of an intravenous injection of Neostigmine 0·6 milligrammes.

Figure 18

Illustration of the attachment of the silver-silverchloride electrodes to the shaved abdominal skin of the rabbit.
NB The lower pair were not in the standard electrode sites (cf Figure 8)

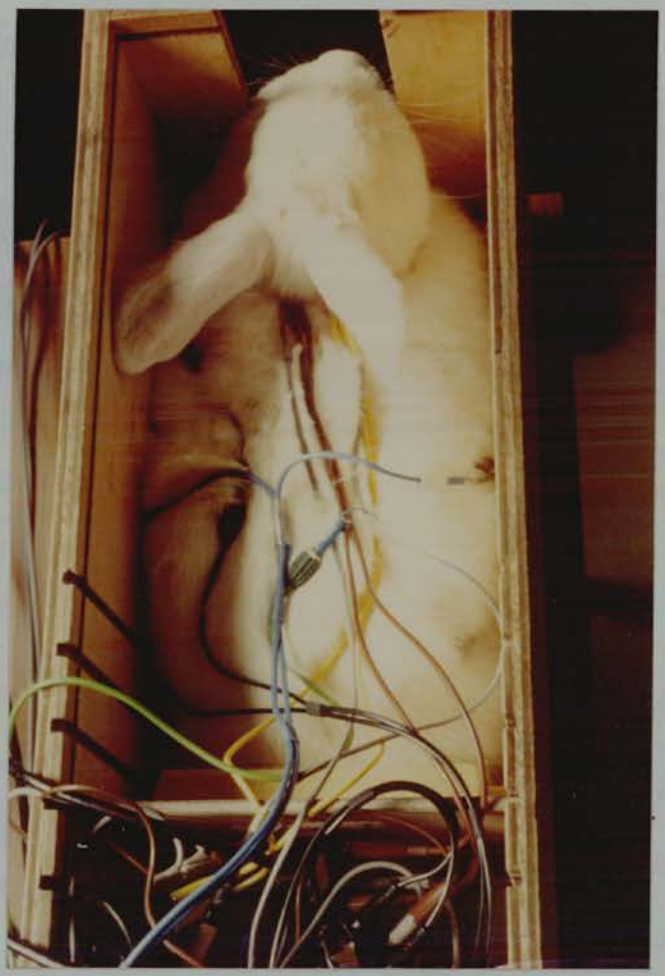


Figure 19

Photograph of the rabbit in the recording box which discouraged movement. The electrical connections to the implanted electrodes were made at the base of the base of the neck and the skin electrode connections were made on each side.

ANALYSIS.

Animal Experiments.

Visual Analysis.

Inspection of the recordings was most important in analysis principally for the following reasons:

1. Variations in patterns of activity were apparent on inspection. Correlation between periods of high amplitude in different recordings were made visually as were the presence of spike potentials and waxing and waning of the slow waves.

2. Choice of indices may be determined on inspection of the traces and enabled a more detailed analysis by computer. For example, duration of spike potential discharge, amplitude of the slow wave or frequency of the slow wave.

3. Artefacts, such as skeletal movement, dislodging an electrode or detachment of an electrical connection all produce recognisable deflections on the recording paper. If a record containing these artefacts were presented to the computer for frequency analysis, biased results will be produced.

Parameters Measured.

Frequency.

The duration, d, of two full slow wave cycles in small squares of the recording paper was divided into 104, the number of small squares in two minutes.

$$\text{Frequency, } f = \frac{104}{d}$$

Estimating frequency over short periods allowed an average frequency to be calculated and demonstrated changes in frequency.

Amplitude.

It became clear that, after commencing the electrical recordings, there were distinct periods of activity which occurred in the implanted electrode and the skin electrode recordings. These periods had two factors in common: the presence of spike potentials (in the implanted electrode recordings) and an increase in amplitude. Frequency correlation during these periods was disappointing and in view of findings in the later experiments, the amplitude changes were examined.

Increase in amplitude greater than twice basal amplitude was recognised as occurring over short periods. The total duration of these high amplitude periods (HAP) was measured and expressed as a percentage of the recorded time.

In correlation studies, the incidence and timing of the High Amplitude Period was noted in synchronous recordings from two different electrodes

i.e. skin electrodes and implanted electrodes. A positive correlation occurred when the high amplitude periods were detected by both methods at the same time and a zero correlation when the HAP was detected by only one method.

Spike Potentials.

Spike potentials were detected only from the implanted electrodes and were not observed in the skin electrode recordings. However, not all the implanted electrode recordings showed the presence of spike potentials and where they were detected, the spike potentials were seen only during periods of increased amplitude. The slow wave activity and the correlation between the two electrode recording techniques was of primary importance. Consequently, the presence and duration of spike potentials was not analysed although recognition was made of their intimate relationship with the "high amplitude periods".

Motility Index.

In the experiments where neostigmine was used to stimulate the colon, a "Motility Index" was derived by replaying the tape recorded signals into an electronic device which calculated the total area under the waves in a given period of time. This was achieved by band-pass filtering from 1 cycle per minute to 30 cycles per minute (Kemo Filter Type VBF-14) to centre the signal baseline, followed by precision full wave rectification to convert negative waves to positive. The signal was then integrated to give an output voltage proportional to the summated wave area in a given period. This output signal, whose value for a 30 minute period was taken as the Motility Index, was displayed on one channel of

the chart recorder. Equal time periods were used before and after stimulation.

Statistical Methods.

Visual inspection suggested that the indices were normally distributed so parametric statistical analyses were applied.

Paired "t" Test.

All the results of the Motilty Indices were paired before and after stimulation and the paired "t" test was an appropriate method to apply.

Chi squared and Exact Probability Test.

In the human colon motility studies with the Strain Gauge Probe, Section 2, chi squared analysis with Yates correction was applied. The Exact Probability test was employed to calculate p values in some cases where the mumbers were small.

Computer PDP-11/34.

A DEC PDP-11/34 computer was used to perform the cross correlation and Power Spectral Density analyses on the data stored on magnetic tape. Two channels of recording were replayed from the the FM tape recorder at 64 times greater than recorded speed. The replayed signal was passed through a narrow band pass filter (Kemo Dual Variable Filter Type VBF/14 set to have attenuation outside the passband of 24 dB/Octave) with the high frequency cut off set at 30 Hertz which was roughly equivalent to 28 cpm at recorded speed. This filtering, which is a standard computer

procedure for handling analogue signals, is said to be necessary to prevent "aliasing" i.e. the false representation of higher frequencies in the low frequency range. The sampling rate was set at 64 Hertz, remembering that the replay speed of the recorded signals was 64 times recorded speed.

Having acquired the data the computer was able to perform various functions.

1. Frequency analysis
2. Power content at various frequencies
3. Cross correlation of two recordings taken simultaneously.

Frequency analysis was possible by applying a Fast Fourier Transform (FFT) algorithm to the data. However a Power Spectral Density (PSD) was more useful in that it used the fourier transform to provide a plot of energy content (expressed as the square of amplitude, V^2) for every frequency component of the signal i.e. it plotted V^2 against f. To obtain the energy within a given frequency range, the area under the curve so produced may be integrated between any limits of interest. This value may then be obtained from other frequency ranges within the same record or within a similar frequency range from other recordings.

Cross Correlation

Cross correlation of two simultaneously acquired signals enabled a comparison between the two recordings within preset limits so as to determine whether one signal was represented in the other beyond random chance. This was particularly useful in comparing two different methods

of recording the same event e.g. skin and implanted electrodes in detecting the frequency of the electrical signals from the colon. The signal obtained from the skin electrodes at one instant of time (To) was compared with the signal obtained from the implanted electrodes at some other instant in time (Tn). For each instant in the recording from the skin electrodes this process was repeated for one hundred instants of the record from the implanted electrodes i.e. fifty before and fifty after To, before moving onto the next instant of the skin electrode record at which the process was repeated.

SECTION 1

THE ANIMAL EXPERIMENTS

Evaluation of Skin Electrodes in the Detection of Colonic Myoelectrical Activity.

EXPERIMENT 1.

Before recording from skin electrodes on the rabbits, it was necessary to record from the intestinal smooth muscle with implanted electrodes in order to form a basis for comparison with later recordings from the skin electrodes.

The aim of this experiment was to identify the differences in the frequency, amplitude and configuration recorded from the different components of the gastrointestinal tract.

Method.

Bipolar stainless steel electrodes were implanted into the muscle layer of the intestinal muscle in seven rabbits. Details are described in the General Methods Section.

Sites of electrode implantation:

a. Body of Stomach
b. Antrum
c. Jejunum
d. Caecum
e. Colon - proximal
f. Colon - distal
g. Rectum

There remains some confusion in the literature (Jule, 1974) between the distal colon and the rectum in the rabbit. The rabbit has a long rectum with a circumferential longitudinal muscle layer. In contrast, the colon resembles the anatomy of the human colon with its taenia and sacculations. For the purpose of this study the above definitions stand.

The animals were allowed to recover fully from the anaesthetic and the operation and were all eating and defaecating normally. Each animal was recorded sequentially over 5-10 days starting 48 hours after the operation.

The frequency of the electrical activity was calculated by counting

the number of small squares between two full cycles or three wave peaks and dividing this into 104 (the number of small squares in two minutes). The colon electrical activity was irregular in frequency and for this reason each consecutive wave length was determined over ten minutes.

Results.

a. Body of Stomach.
A very low amplitude (0·5 mV) wave was detected in the muscle of the body of the stomach. This had a simple continuous waveform and a frequency of 2·5 - 3·5 cpm) and is illustrated in the upper trace of Figure 25.

b. Antrum.
A high amplitude (1-1·5 mV) electrical rhythm with a frequency of 2·5 - 4·5 cpm was detected in the antral smooth muscle (Figure 20). The slow wave occurred in intermittent series of 3 - 5 slow wave cycles with intervening periods of low activity.

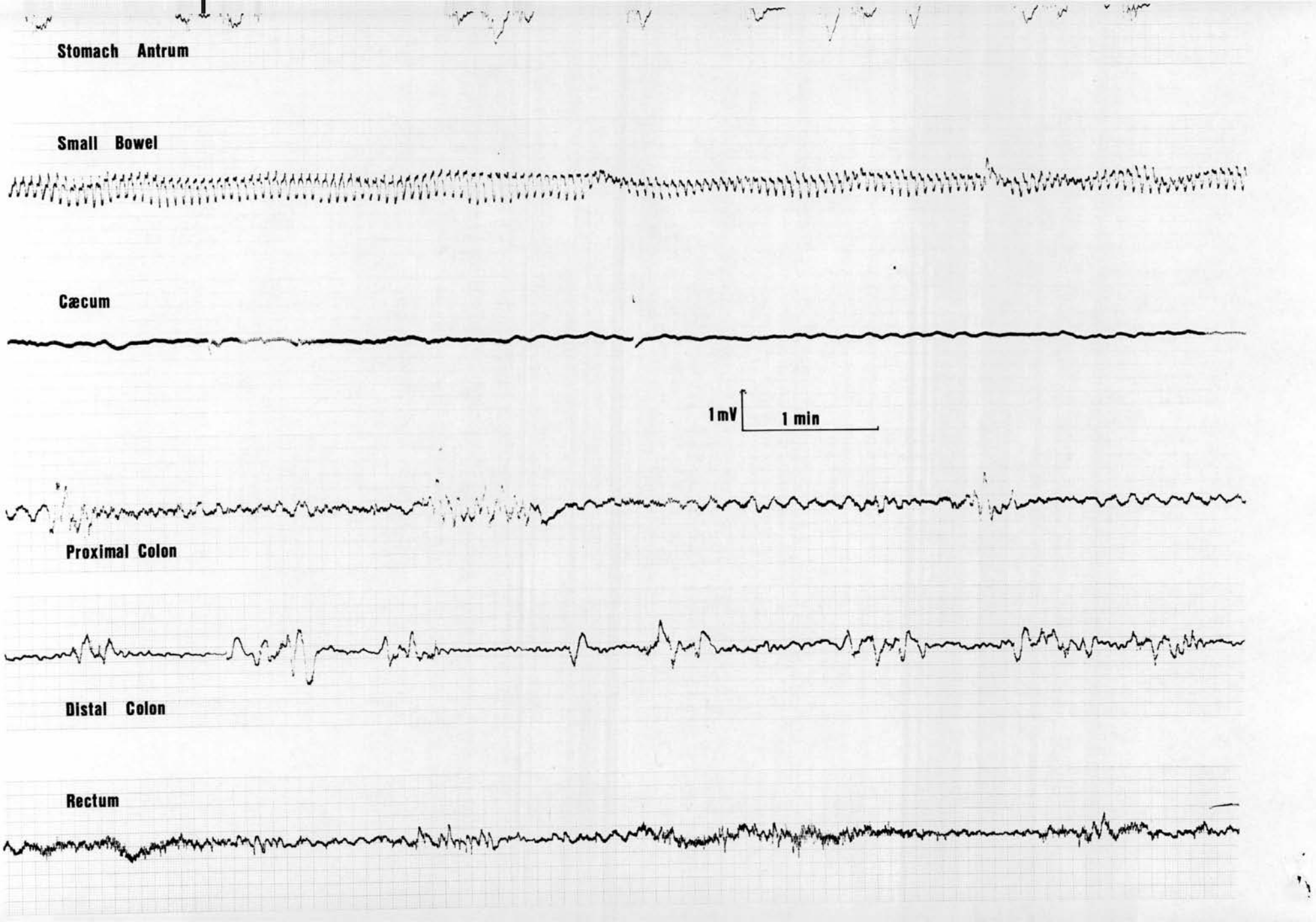
Spike potentials were recorded in rapid succession around the peak of the slow wave in 75% of recordings (Figure 20).

c. Jejunum.
A continuous slow wave with a constant frequency (13 cpm at this site) was recorded from the jejunum. The amplitude was 0·5 mV excluding the spike potentials which were observed as single spikes on the peaks of the slow wave (Figure 20). Waxing and waning of the slow wave was observed in 10% of the recordings.

d. Caecum.
A very low amplitude (0·2 mV) waveform was detected from caecal smooth muscle at a frequency of 5 cpm but no spike potentials were evident on any of the recordings (Figure 20).

Figure 20

Electrical Activity of various parts of the gastrointestinal tract of the rabbit detected by implanted electrodes. Note the continuous activity of the small intestine, the intermittent periods of high activity in the antrum and colon, and the spike potentials in the antrum, small intestine and rectum and less obvious in the proximal colon.


Stomach Antrum
Small Bowel
Cæcum
1 mV
1 min
Proximal Colon
Distal Colon
Rectum

e. Colon.

The taenia of the proximal and distal colon showed a complex electrical activity. There were intermittent periods characterised by an increase in amplitude greater than twice basal amplitude and also by the presence of spike potentials which were never detected outside these periods. These periods have particular relevance in later experiments and have been termed High Amplitude Periods (HAP).

In the proximal colon, the periods between the HAP's had a slow wave mean frequency of 7·4 cpm ±1·5 (1 standard deviation). In contrast, this frequency doubled to 15·1 cpm ±1·4 (1 standard deviation) during the high amplitude periods, (Table 4).

In the distal colon, there was less activity in the intervening, "resting" periods which made the high amplitude periods more prominant. The frequency during the high amplitude periods was 8·5 cpm ±0·5 (1 standard deviation) and in the intervening periods the frequency was 16 cpm ±0·2 (1 standard deviation), Table 4.

f. Rectum.

The rectal smooth muscle produced a continuous slow wave rhythm with intermittent, continuous discharges of spike potentials lasting 30 - 90 seconds. Any change in slow wave frequency which might have been present during these periods of spike potential discharge was masked by the spike potentials themselves. An increase in amplitude was not a feature of the periods of spike activity in the rectal muscle.

Discussion.

The electrical activity of the various parts of the gastrointestinal tract has features which were characteristic of that region. Although the frequency range of the slow wave from different parts of the intestine may overlap, other features such as the High Activity Periods, identified the origin of the electrical signal.

The two relatively silent areas, body of stomach and caecum, represented areas which were relatively inactive in mechanical

activity.

The size of the tip of the electrode implanted into the intestinal muscle was such a size that contact with many smooth muscle cells was inevitable. This implies that the recorded electrical activity was detected from multiple smooth muscle cells. It is thought that muscle cells adjacent to each other form a muscle unit. All of the cells in the unit have the same electrical rhythm and the cell or unit with the most rapid electrical rhythm will drive adjacent muscle cells at the faster rate. Hence, the recorded slow wave frequency would be the frequency of the most rapidly oscillating smooth muscle cells. This is the coupled oscillator theory which has been described above.

Frequency doubling of the slow wave was detected in the taenia of the proximal colon during periods of high amplitude. If one applied the coupled oscillator theory then this suggests that a second oscillator, firing at the faster rate, was overriding the previous oscillator. In addition to the frequency doubling, the amplitude increased significantly (at least twice basal levels) and, where spike potentials were detected, they occurred only during these periods - the High Amplitude Periods and were never observed without an increase in amplitude. It is possible that the spike potentials in summation with the slow wave increase the amplitude of the recorded signal although this does not explain the observation that the frequency altered during these periods. More difficult to explain is converse alteration in frequency between the proximal and distal colon, i.e. the frequency during the high amplitude period increased in the proximal colon and decreased in the distal colon.

The association of a rise in amplitude, increase in slow wave frequency and the initiation of spike potentials appeared to be a feature of the colon in the rabbit. Apparent overemphasis of these High Amplitude Periods is discussed after further experiments and their relevance clarified.

TABLE4

A comparison of the slow wave frequencies detected from the proximal and distal colon in the low and high amplitude periods. The wavelengths were measured directly and the frequencies calculated for each wave. The Mean, Standard Deviation, Standard Error of the Mean and the Multiple of the Standard Error of the Differences was calculated.

	Proximal Colon	Distal Colon	Proximal & Distal Colon
Low amplitude period			
Mean Frequency	15·12	16·07	15·52
Standard Deviation	0·203	0·170	0·139
High amplitude period			
Mean Frequency	7·17	8·53	7·68
Standard Deviation	0·265	0·519	0·264
Standard Error of Mean	0·333	0·546	0·298
Difference between Means	7·95	7·54	7·838
Multiple Standard Error of the Differences	23·85 SD	13·82 SD	26·3 SD
	$p < 0·001$	$p < 0·001$	$p < 0·001$

There was a highly significant difference in the frequencies detected during the high amplitude and low amplitude periods in both the proximal and distal colon.

Experiment 2.

Skin Electrical Activity.

It is conceivable that the electrical activity detected by skin electrodes might be generated by artefactual means originating at the interface between electrode and skin or affected by the electrode composition.

To test this hypothesis, two different types of electrode were used to detect the electrical potential variations on the skin. One set of electrodes were the silver - silver chloride discs (Ormed) with electrode gel providing contact between electrode surface and the skin. The other set of electrodes were 34 SWG stainless steel wire electrodes which were implanted intradermally adjacent to the silver - silver chloride electrodes.

Method.

At laparotomy, under general anaesthesia, two pairs of stainless steel electrodes were implanted intradermally in the standard skin electrode sites in two rabbits (Figure 8). Full details of the anaesthesia and electrode insertion are given in the General Methods Section.

Following complete recovery from the anaesthetic, 48 hours later, silver-silver chloride electrodes were attached to the shaved abdominal skin in the four standard skin sites, adjacent to the stainless steel electrodes. Care was taken to place the silver-silver chloride electrodes sufficiently far away to prevent a short circuit or interference.

Bipolar recordings were taken from the two pairs of stainless steel and two pairs of silver-silver chloride electrodes for sixty minutes.

Correlation was determined by visually comparing the two recordings for incidence and timing of the High Amplitude Periods.

Results.

Both types of skin electrode detected wave-like variations in electrical potential and there was no significant difference in the electrical activity detected by the two methods. The electrical activity detected by the transverse silver chloride electrode pair was almost identical to the stainless steel electrode pair implanted at the same site. The same was true of the longitudinal electrodes, but differences in wave pattern was noticed between the longitudinal and transverse electrode sites.

However, none of the recordings compared closely to the electrical activity of the various parts of the intestinal tract recorded in Experiment 1 with regard to the regularity of the waveform. The frequency of the waveforms detected by the skin electrodes varied from wave to wave, with a range of 3 - 22 cpm. However, on inspecting greater lengths of recording, it was apparent that, in similarity with the proximal and distal colon in experiment 1, the amplitude varied between periods of low amplitude to periods of high amplitude, where the increase in amplitude was twice or more than basal levels. The amplitude ranged from 0·1 - 1·5 mV. The High Amplitude Periods were detected simultaneously by both types of skin electrode.

Discussion.

It was clear that rhythmic variation in electrical potential, whatever their origin, were detected by the skin electrodes, and moreover, the site of the electrode attachment determined the minor differences in waveform. By contrast, the differences in composition of the electrodes had little or no part to play.

The origin of the electrical potentials detected by the skin electrodes was not identified in this experiment but it is unlikely that they were generated by the electrodes themselves. If these potentials were generated by the skin electrodes then it would be necessary to postulate a mechanism whereby both types of electrode and both methods of insertion were involved simultaneously. This state of affairs could be produced by movement of the electrodes at their site

of contact with the skin. However this is unlikely because silver/silver chloride electrodes have very low electrode potential values.

This experiment suggests that not only can skin electrodes, situated on the abdomen, detect rhythmic variation in electrical potential with a frequency content and amplitude within the range detected from the intestinal smooth muscle, but there was no difference in comparing the composition of the skin electrodes or the method of insertion/attachment to the skin. In addition, the origin of the electrical potentials detected by the skin electrodes, lies within the body of the rabbit and is unlikely to be an electrode generated artefact.

Experiment 3.

Experiment 2 showed that electrodes attached to the skin detected fluctuations in electrical potentials which were considered not to be electrode artefacts. The electrodes in Experiment 2 were attached to the abdominal skin in bipolar fashion and the origin of these potentials is in question. The skin or subcutaneous tissues might be the source of these potentials in which case electrodes attached to other sites around the body should detect similar potentials. In contrast, the electrical potentials might have a point source some distance away from the electrodes and transmitted to the skin via nerves or blood vessels or the tissues in general. With this consideration, silver-silver chloride electrodes were attached to the skin of the rabbit at various parts of the body in order to determine the effect of electrode site on the electrical activity detected.

Method.

Two pairs of stainless steel electrodes were implanted into the taenia of the proximal and distal colon in six rabbits which were allowed to recover fully from the anaesthetic.

Forty eight hours later, bipolar silver-silver chloride skin electrodes were attached to the shaved skin at the following sites: (Figure 21)

1	Abdominal	Right-left transversely	2- 3
2	Abdominal	Longitudinally	1- 4
3	Abdominal	Antero-posteriorly	5- 4
4	Thoracic	Transversely	6- 7
5	Oblique trunk	Left thorax-outer thigh	7- 8
6	Thighs	Left outer thigh-right outer thigh	8- 9
7	Thigh	Right outer thigh - right inner thigh	8-10

Recordings of electrical activity from the implanted electrodes were compared with the electrical activity detected from the skin electrodes and analysed for the presence of High Amplitude Periods (HAP) and previously recognised wave-like fluctuations in electrical potential.

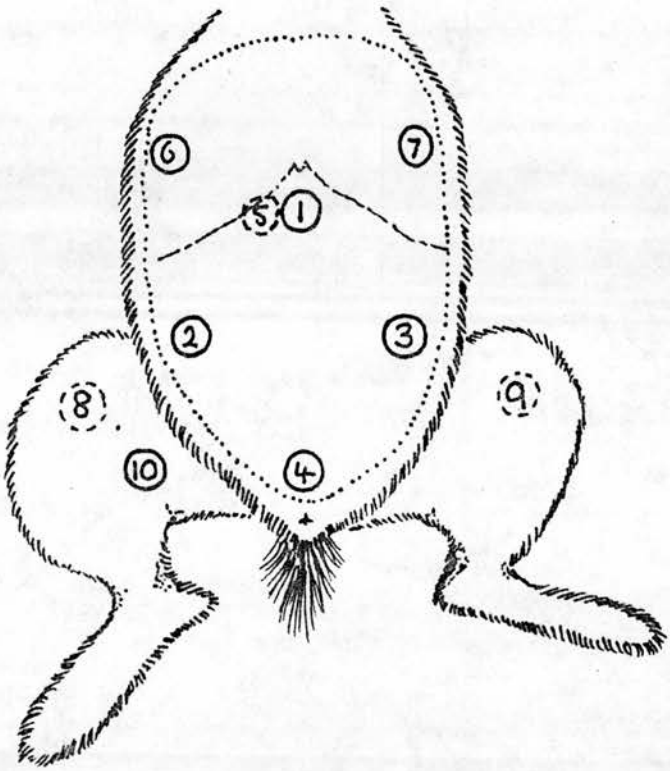
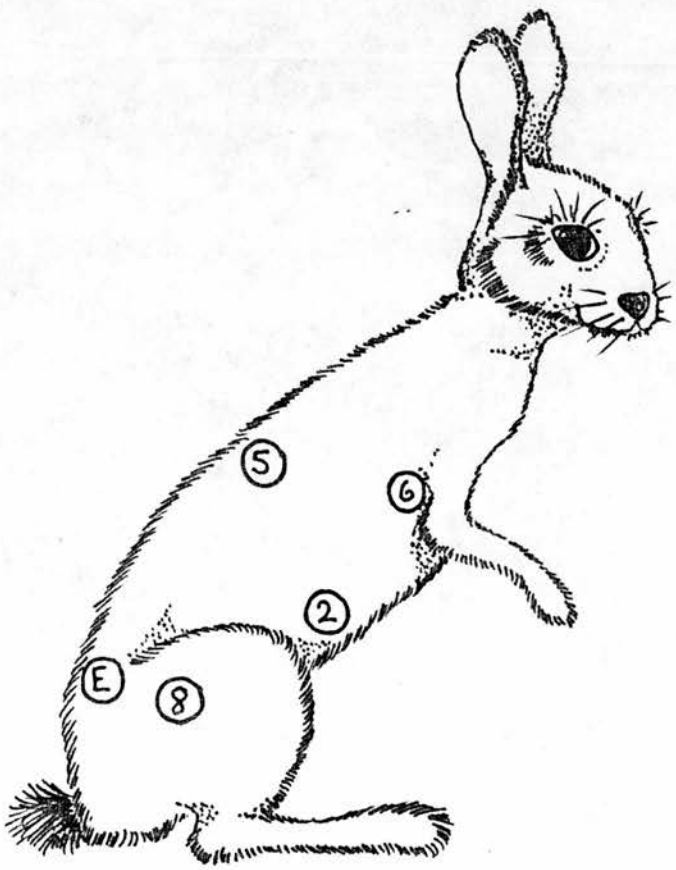


Figure 21. Diagram illustrating the site of skin electrode attachment to the rabbit's shaved skin.
Interrupted circles refer to dorsal sites of attachment.



Results.

The implanted electrodes detected the electromyographic pattern characterised by a low amplitude wave interspersed by periods of high amplitude lasting 30 - 90 seconds, (the high amplitude periods).

Sites 1,2,3,5 & 6 detected variable fluctuations in electrical potential with intermittent High Amplitude Periods. These periods were the same as those detected by the electrodes implanted into the taenia. All the above electrode sites had the abdomen situated between the bipolar electrodes.

Site 4, the transverse thoracic electrodes, recorded respiratory movement artefact only. There was no cardiac electrical activity detected nor any fluctuations in electrical potential resembling the waveforms detected at sites 1,2,3,5 and 6.

Site 7, recorded across the surface of the right thigh, revealed a flat electrical recording interspersed with bursts of high frequency when skeletal movement occurred.

Discussion.

All the electrode pairs which had the abdomen between the poles of the electrodes detected fluctuations in electrical potential which had considerably greater amplitude than the remaining electrodes. In addition, the episodes of high amplitude had a periodicity and their duration 30 - 90 seconds was identical to that of the high amplitude periods detected by the implanted electrodes. A more detailed analysis of the correlation between the two recording electrode methods and the high amplitude periods is undertaken in later experiments and was not the remit of this experiment.

The two sites, which did not have the abdomen situated between their poles (thorax and thigh), demonstrated no intermittent episodes of high amplitude. The electrode pair situated across the thorax detected a low amplitude (0·1 mV) regular frequency 30 - 40 cpm, which was greater than any of the frequencies recorded from the intestinal smooth muscle and

exactly corresponded with the respiratory excursions of the rabbit. An electro-cardiogram was not obtained due, most likely, to the superimposition of one ventricular complex upon another but other factors, such as the axis of depolarisation of the cardiac muscle and the internal parameters of the recording amplifiers might contribute to this.

This experiment suggests that the electrical activity, previously detected by the skin electrodes, originates in the abdominal area and theoretically may involve any of the tissues in this area including the intestines. Voluntary muscle and cardiac muscle would appear to be most unlikely sources considering the absence of this electrical activity from the electrodes at sites 4 and 7.

EXPERIMENT 4

Correlation of skin electrical potentials with electrical events in the intestinal smooth muscle.

Experiment 1 showed that the antrum and the colon smooth muscle were sources of electrical activity which had intermittent periods of high activity. It would appear most likely that one or other of these was the source of the high amplitude electrical activity detected by the skin electrodes.

In this experiment, the electrical activity detected by electrodes implanted into the colon and antrum were compared with the activity detected by skin electrodes attached to the abdomen.

Method

Two pairs of electrodes were implanted into the muscle layer of the taenia and the antrum in five rabbits. An extra pair were implanted into the circular muscle between the taenia.

Forty eight hours after the operation, skin electrodes were attached to the abdomen at the standard sites, (Figure 8).

Recordings were taken from the skin and implanted electrodes for sixty minutes and stored on magnetic tape and heat sensitive paper.

Two parameters were analysed: frequency of the recordings and amplitude changes. Cross correlation of the frequency content of the tape recordings from the colonic electrodes and the skin electrodes were compared by computer. Increases in amplitude greater than twice basal levels and lasting for more than 15 seconds were noted. These periods with increased amplitude have been otherwise termed "the High Amplitude Periods" and their incidence in both skin and implanted electrode recordings together with the correlation between the two recording methods was recorded.

Results.

Colonic Electrical Activity

Amplitude.

High amplitude periods were detected by both the skin electrodes and by the electrodes implanted into the colon. There was a good correlation in incidence and synchronicity of the high amplitude periods between the two methods (Table 5).

Figure 22 shows the electrical activity recorded from the circular muscle (1) and taenia (2 and 3) of the proximal colon. High amplitude periods were not detected in the circular muscle recordings in contrast to the taenia where the high amplitude periods were quite evident and correlated well with high amplitude periods detected by the skin electrodes.

Frequency.

Frequency analysis and computer cross correlation showed a poor correlation between the electrical activity recorded by the skin electrodes and the electrodes implanted into the taenia of the colon (Figure 23). This was apparent on inspection, for where the frequency of the slow wave increased during the high amplitude periods detected by the colonic implanted electrodes, the frequency of the slow wave decreased during the high amplitude periods detected by the skin electrodes, (Table 6).

Antral Electrical Activity

The implanted antral electrodes detected intermittent cycles of activity with a frequency of 3±0·5 cpm. The slow wave occurred in groups of 3 - 5 cycles with relatively silent periods between. The amplitude was higher than many other parts of the intestinal smooth muscle and was 1 - 1·5 mV. Spike potentials were observed at the peak of the slow wave.

In contrast, the skin electrodes detected high amplitude periods which showed no relationship or correlation with the antral smooth muscle electrical activity, (Figure 24), nor was there any correlation in frequency between the antrum and skin electrodes.

Discussion

The high amplitude periods detected by the skin electrodes correlated well with colonic high amplitude periods but not with antral electrical activity. In contrast, the frequency of the electrical signal, detected by both skin and implanted electrodes, correlated poorly. This was apparent on inspection, for where the frequency of the colonic slow wave increased during the high amplitude periods, the frequency of the slow wave detected by the skin electrodes decreased during the high amplitude periods.

The reason for the contrasting response in the frequency during these high amplitude periods may be related to:

1/. Spike potentials have been observed only during the high amplitude periods and it may be inferred that motor activity of the smooth muscle was initiated or increased during the high amplitude periods. Hence the summation of spike potentials and slow wave may be the electrical event detected in the skin electrodes as the high amplitude period, (Smout et al, 1980).

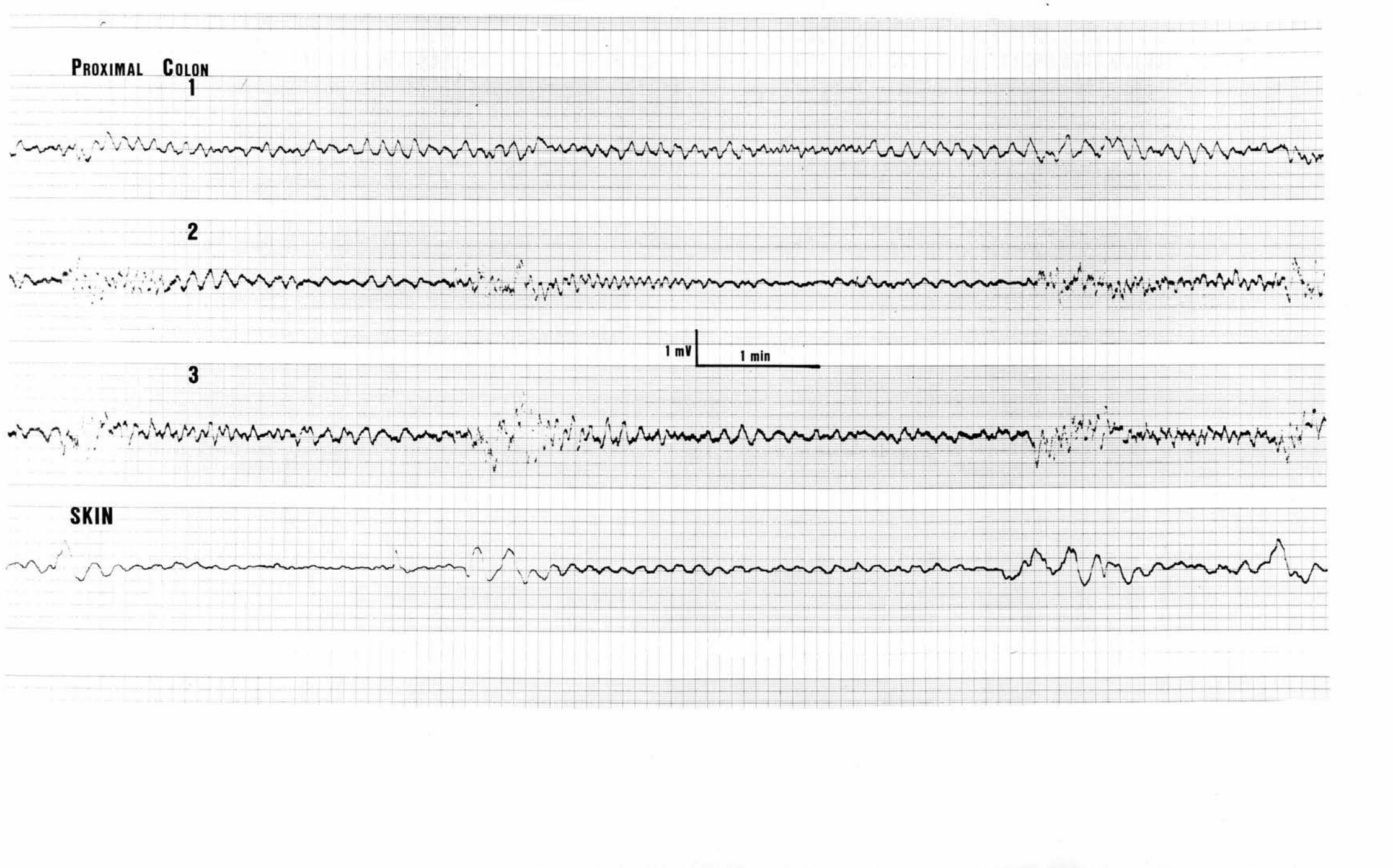
2/. Spike potentials were never observed outside the high amplitude periods nor in the skin electrode recordings. The motor activity produced by the spike potentials might be a factor in the generation or mediation of the high amplitude periods in the skin electrode recordings.

Conclusion

The abdominal skin electrodes detected amplitude changes which correlated best with the high amplitude periods arising from the taenia coli in the rabbit, especially the proximal colon.

Figure 22

Electrical Activity of the proximal colon detected by implanted electrodes (1 - circular muscle, 2 and 3 taenia) and skin electrodes. Note the correlation of High Activity Periods between the skin electrical recordings and the taenia coli but not the circular muscle. Also demonstrated is the variation in frequency of the colon electrical slow wave.


PROXIMAL COLON
1
2
1 mV
1 min
3
SKIN

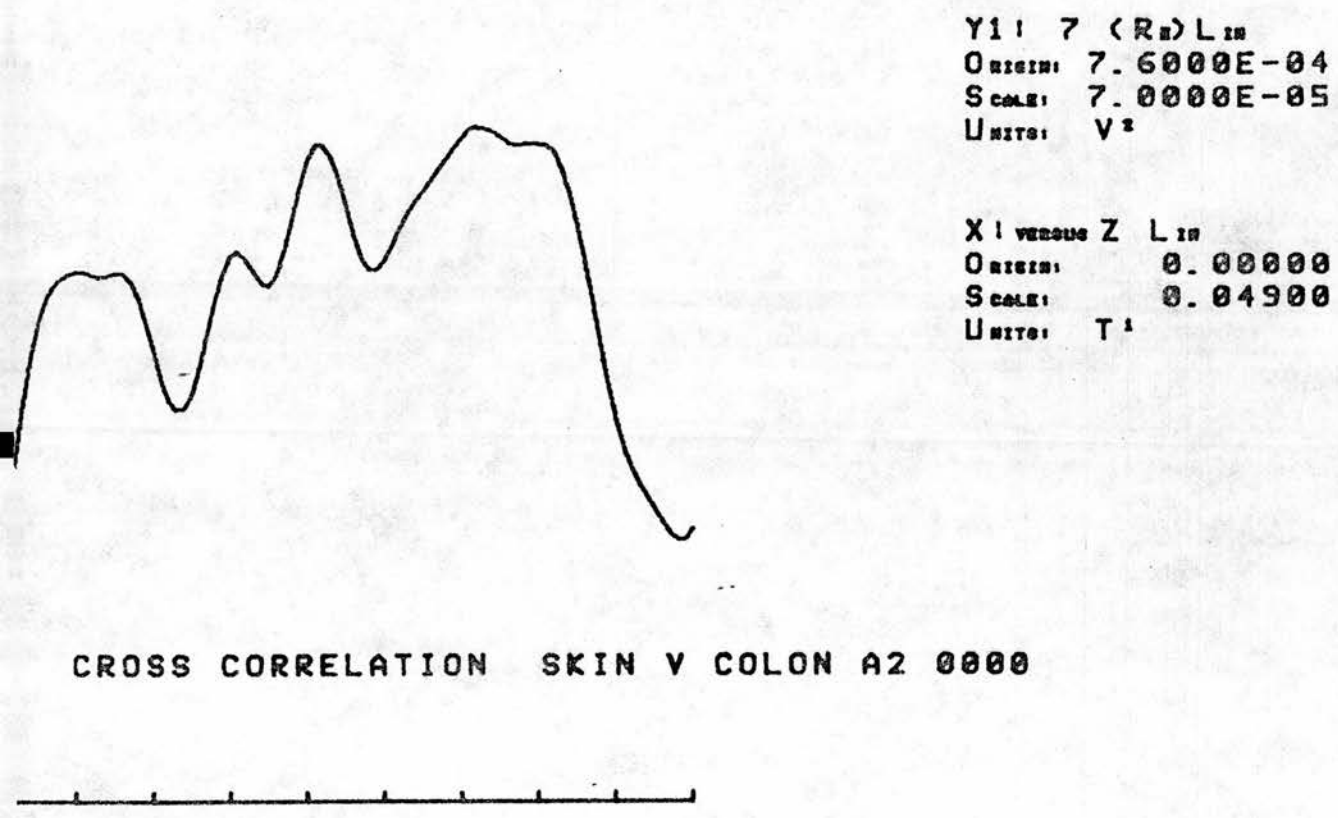


Figure 23

Computer cross correlation of frequency content from skin electrode and implanted electrode recorded activity. The scale on the Y axis is so small, 7×10^{-5}, that no correlation was demonstrated.

Figure 24

Electrical Activity detected by electrodes implanted into the antrum were compared with the skin electrode recordings. No correlation in High Activity Periods was demonstrated.


Filter «1» 2·5 – 4·5 cpm
1
S/S in Antrum
2
1 mV
1 min
3
SKIN
4
Filter «4»
3 – 8 cpm

Table 5

Correlation of high amplitude periods (HAP) as recorded by skin electrodes and electrodes implanted into the taenia of the colon in five rabbits.

	HAP with Correlation		HAP without Correlation	
Rabbit	Skin Electrodes	Implanted Electrodes	Skin Electrodes	Implanted Electrodes
1	34	34	1	0
2	13	13	0	1
3	39	39	0	3
4	25	25	0	6
5	37	37	0	9
Total	148	148	1	19

Total HAPs recorded = 168

HAP with correlation = 148
or 88% correlation

HAP without correlation = 20

TABLE 6

A comparison was made from 273 paired frequencies obtained from recordings of electrical activity detected by skin electrodes and electrodes implanted into the taenia coli. The wavelength of each cycle was measured together with its synchronous pair in the corresponding recording and the frequencies were calculated. A correlation coefficient, r and Student's t were calculated.

n = 273 pairs

Correlation coefficient, r = 8·16E-6

t = 1·3E-4

$p > 0{\cdot}5$

EXPERIMENT 5

Previous experiments have shown that the skin electrodes detected electrical activity arising from the abdomen and comparisons with electrodes implanted into the intestinal muscle indicated that the best correlation was with the taenia of the colon. However, other sources were not excluded, especially the various parts of the gastrointestinal tract.

In this experiment, skin electrical potentials were compared after excision of subunits of the gastro-intestinal tract, e.g. antrum, small intestine, in order to ascertain the effect of such exclusions.

Method

Under general anaesthesia, various parts of the rabbit gastrointestinal tract were excised and recordings were taken from two pairs of skin electrodes at the standard sites. In some cases, implanted electrodes were included to aid comparison.

a. Excision of gastrointestinal tract

In three rabbits, at laparotomy, the blood supply to the stomach, duodenum, small and large bowel, caecum and appendix and rectum was ligated and divided before excising the gastrointestinal tract from fundus of stomach to lower rectum, including pancreas and spleen. A short length of stomach was left attached to the oesophagus and a gastrostomy formed for the drainage of saliva.

b. Excision of colon

In four rabbits the blood supply to the taenia bearing colon was ligated and divided and the colon excised between non-crushing clamps applied to the upper rectum and caecum. An end to side anastomosis between the rectum and caecum was performed with 3/0 chromic catgut in one layer. Stainless steel electrodes were implanted into the stomach antrum.

c. Excision of Antrum

In four rabbits, the lesser omentum and greater omentum attached to the antrum was ligated and divided between non-crushing clamps.

The duodenum was mobilised by Kochers manoeuvre and anastomosed end to end to the body of the stomach with a single layer of 3/0 chromic catgut.

d. Excision of small bowel

In four rabbits the small bowel mesentery supplying jejunum and ileum was ligated and divided. The distal duodenum, jejunum and ileum were excised and the caecum anastomosed to the duodenum with a single layer of 3/0 chromic catgut.

Recordings were taken from the skin electrodes placed on the rabbit's abdomen after it had fully recovered from the anaesthetic. Two of the three rabbits whose gastrointestinal tract was excised died within 18 hrs of the operation. The third was conscious, alert although not taking food. Recordings of electrical activity were taken from skin electrodes attached to the abdominal skin at the standard sites.

Results

a. Excision of the gastrointestinal tract resulted in minimal electrical activity in the skin electrode recordings apart from a low amplitude, simple waveform which had a frequency 3cpm. The only remaining part of the gastrointestinal tract was the small portion of stomach that formed the gastrostomy. Previous recordings from different regions of the gastrointestinal tract showed a simple low amplitude 3 cpm frequency recorded from the body of the stomach in an earlier rabbit. This earlier recording is shown as the upper trace in Figure 25 and the lower two are the electrical activity recorded from the skin electrodes in the rabbit whose gastrointestinal tract was excised.

b. Excision of the colon resulted in a distinct diminution of electrical activity detected by the skin electrodes. Figure 26 illustrates the activity detected before and after the colectomy. The most noticeable difference is the lack of the high amplitude periods after the colectomy. Electrodes implanted into the antrum show the presence of 3 cpm slow wave electrical activity of high amplitude but no representation of this is apparent in the electrical activity detected by the skin electrodes.

c. Excision of the antrum had little effect on the electrical activity detected by the skin electrodes. There were intermittent periods of increased activity with high amplitude periods detected by the skin electrodes which coincided with the high amplitude periods detected by electrodes implanted into the taenia of the colon, (Figure 27).

d. Excision of the small intestine.
The skin electrodes detected little noticeable difference after excision of the small intestine. High amplitude periods persisted after the resection. (Figure 28).

Discussion

Once again the skin electrodes detected high amplitude periods which correlated well with amplitude changes in the stainless steel electrodes implanted into the taenia of the colon. In contrast, no high amplitude periods were detected by the skin electrodes when the colon had been excised. During the colon-excision experiments the stainless steel electrodes were implanted into the antrum of the stomach which confirmed the persistance of the high amplitude slow wave. The absence of the skin high amplitude periods when the colon had been excised and the good correlation between skin and electrodes implanted into the taenia was good evidence that the two methods of detecting electrical activity were recording the same event, namely the high amplitude periods.

The High Amplitude Periods

Much importance has been made of these high amplitude periods and relatively little of the frequencies of the electrical signals. However, in the course of these experiments, the frequency content of the intestinal (colonic) smooth muscle had no detectable representation in the frequency detected by the skin electrodes. In contrast, there was a clear and obvious correlation between sustained amplitude increases detected by both recording techniques.

The high amplitude periods must have some physiological significance and this was most likely related to the presence of spike potentials which were detected during the full duration of the high amplitude periods and never outside these periods (in the colon). It is known that spike potentials initiate contractions and the more spike potentials so the stonger the contraction. It is a reasonable presumption that the high amplitude periods indicate that the colon was undergoing a period of contraction. By contrast, in the intervals between the high amplitude periods where the amplitude was low, so the contraction activity was similarly low.

Figure 25

The electrical activity detected by skin electrodes following excision of the gastrointestinal tract. A gastrostomy was performed and the upper tracing was recorded from implanted electrodes in the body of the stomach of the intact rabbit at another recording. Note the similarity in the waveform present in both sets of recordings. It is most probable that the remaining portion of stomach forming the gastrostomy was the source of the low amplitude simple waveform.

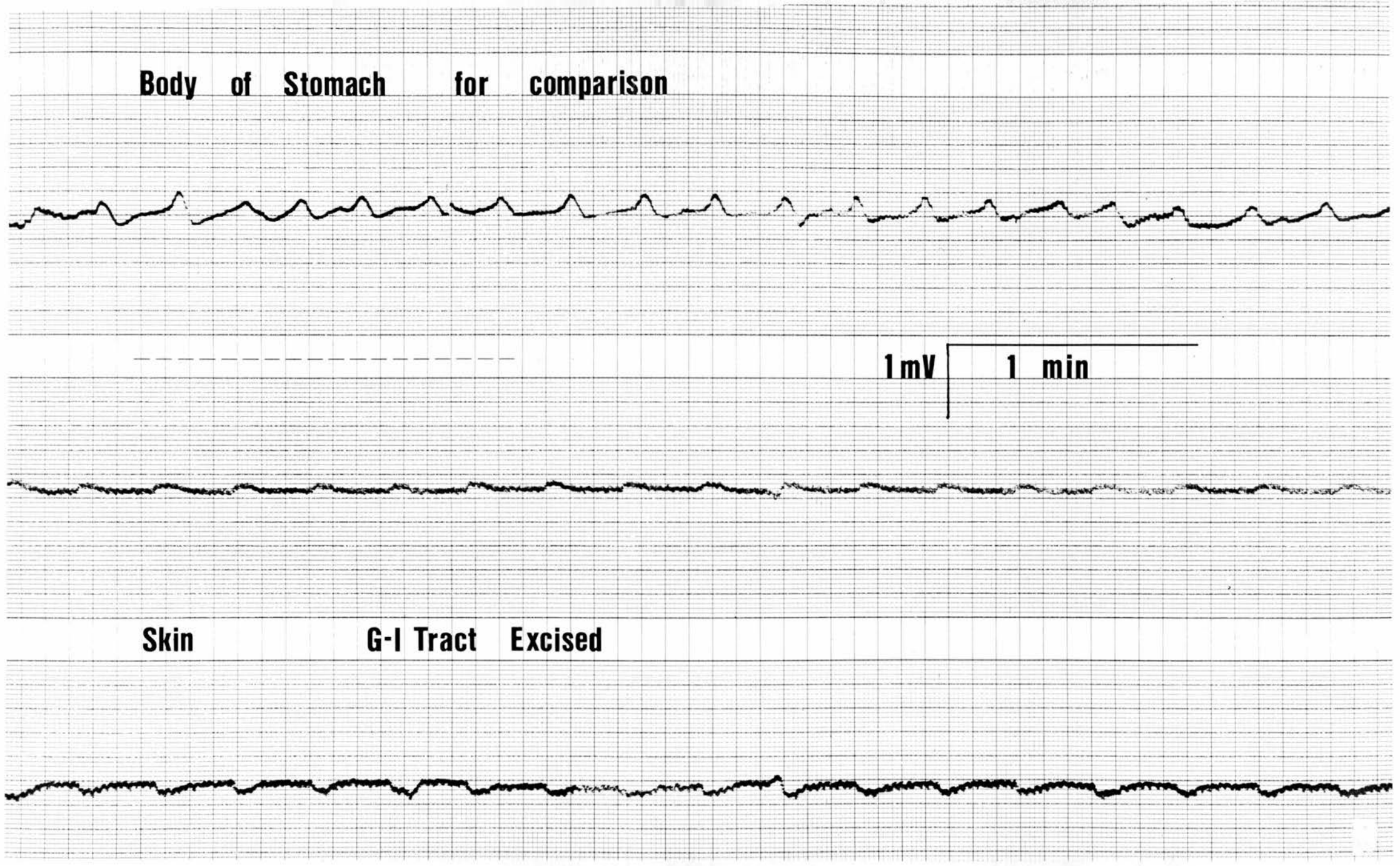

Body of Stomach for comparison
1mV
1 min
Skin
G-I Tract Excised

Figure 26

The electrical activity detected by skin electrodes before excision of the colon (1 and 2) and after colectomy (3 and 4).
Note the absence of high amplitude activity following excision of the colon.

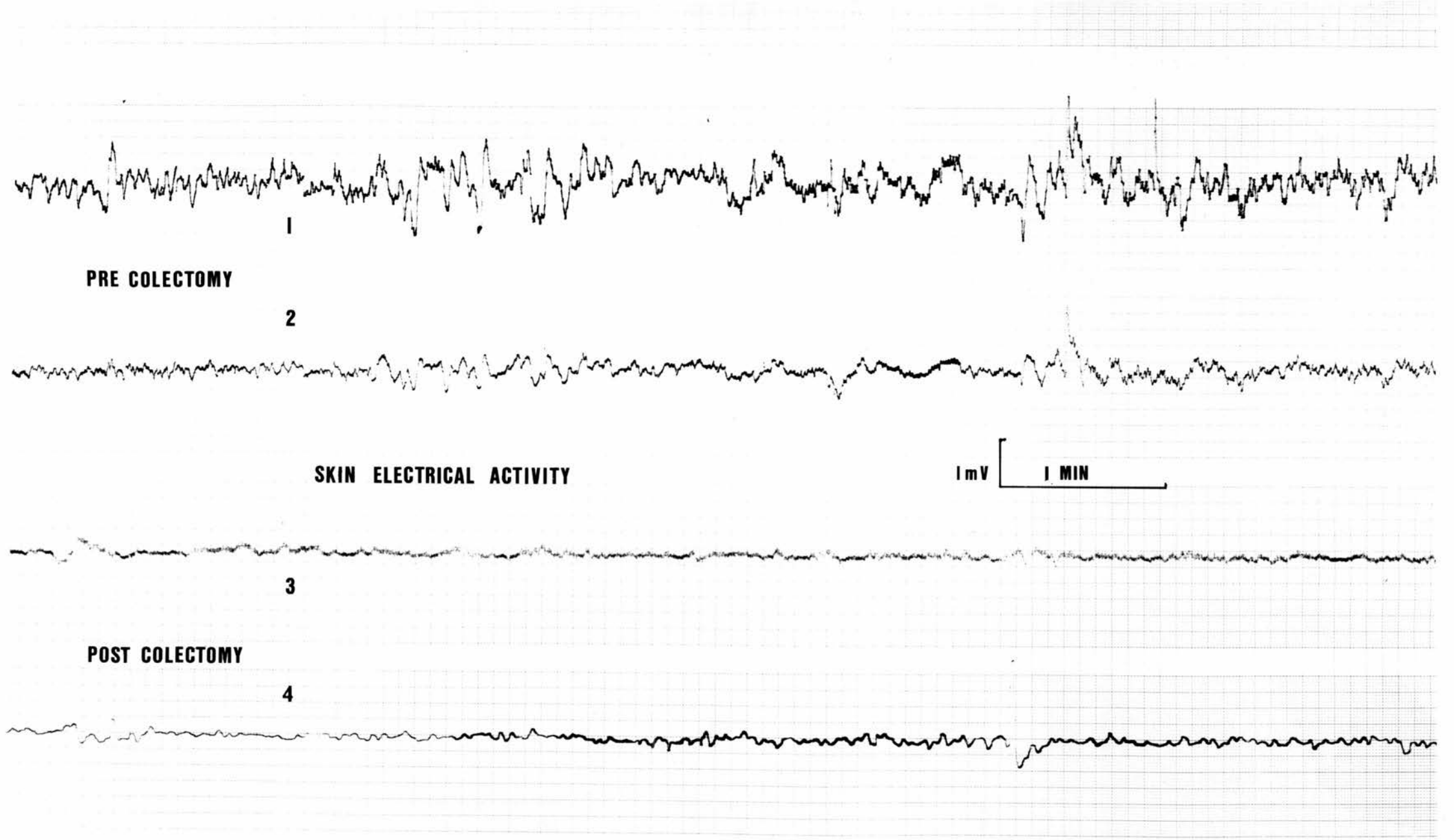

1
PRE COLECTOMY
2
SKIN ELECTRICAL ACTIVITY
1mV
1 MIN
3
POST COLECTOMY
4

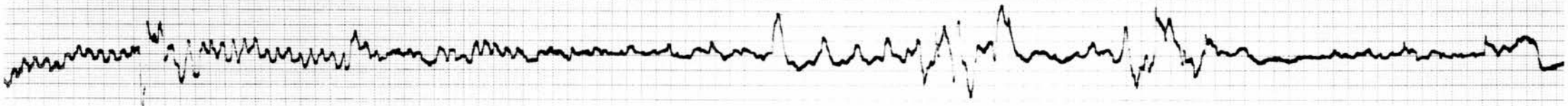
Figure 27

The electrical activity following antrectomy. Upper trace shows the electrical activity detected by stainless steel electrodes implanted into the taenia coli. The lower traces show the electrical activity detected by skin electrodes.

Note the persistence of the High Activity Periods and the correlation between the implanted colonic electrodes and the skin electrodes.

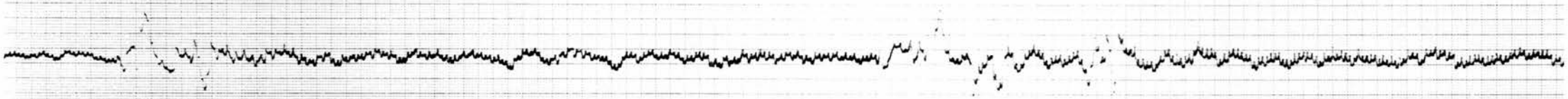
Post Antrectomy

S/S COLON



1mV

1 min



transverse pair

SKIN ELECTRODES

a/p pair

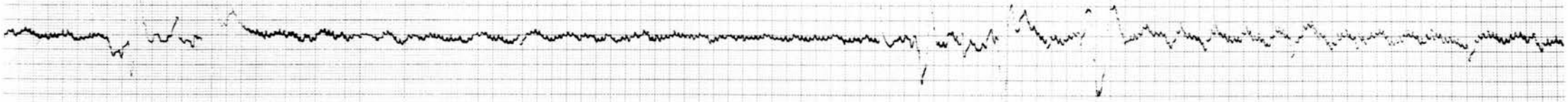
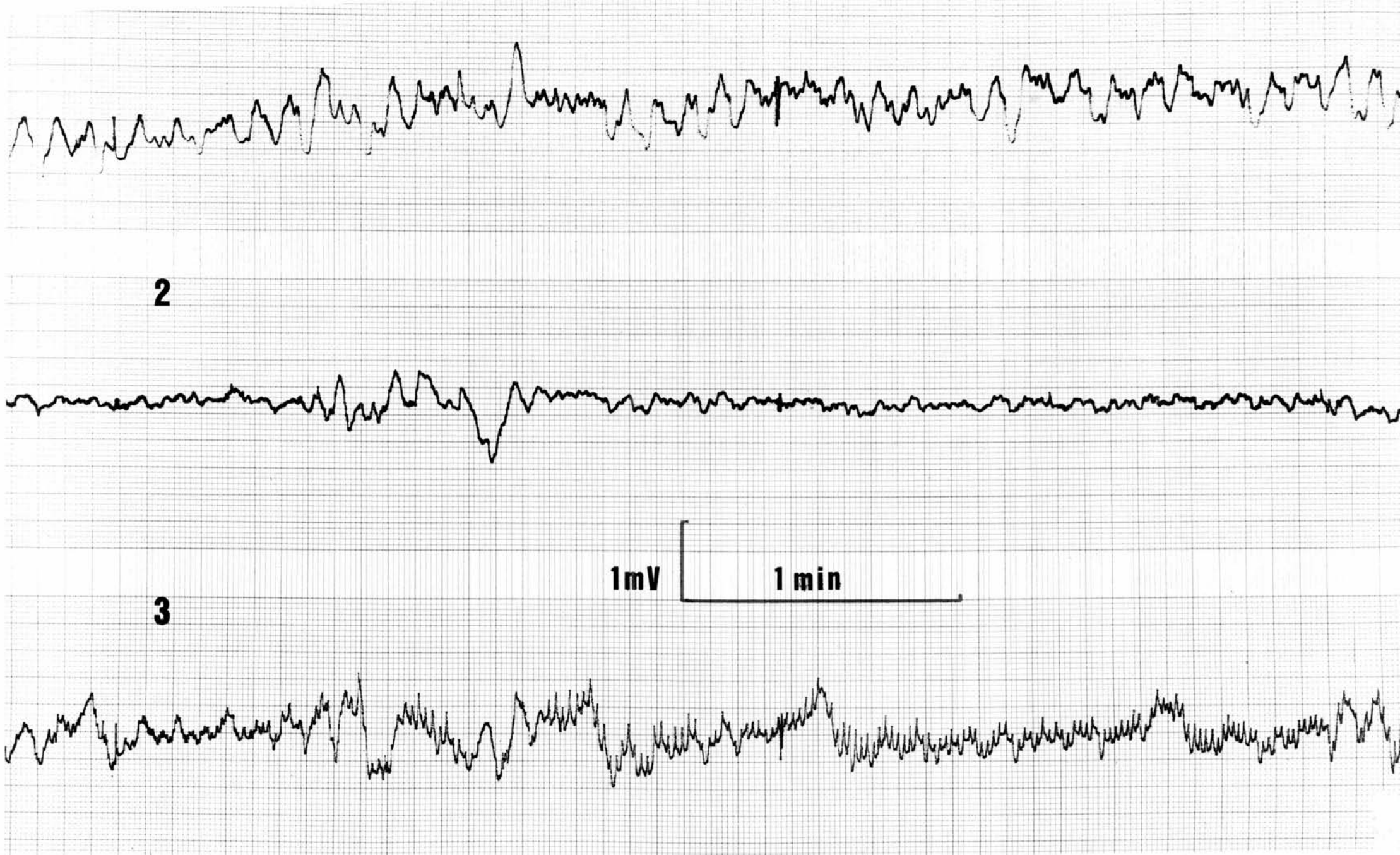


Figure 28

The electrical activity detected by skin electrodes following excision of the small bowel.

Note the persistence of high amplitude electrical activity.


2
1mV
1 min
3

EXPERIMENT 6. The subcutaneous colon.

The high amplitude periods detected by the skin electrodes on the abdominal skin correlated well with the high amplitude periods detected by the electrodes implanted into the taenia coli. Thus, correlation of amplitude changes was good, but, in contrast, correlation in frequency was poor.

The absence of frequency correlation between the two types of recording electrode is not clear. Certainly, some of the signal from the colonic smooth muscle (in the rabbit) was detected by the skin electrodes as is evident from the correlation in amplitude changes. It is possible that the thickness of tissue through which the signal has to pass acts as a barrier or in some way dampens the signal. The colon within the abdominal cavity is in close proximity to other loops of bowel, some of which may interpose themselves between the colon and the abdominal wall.

In order to prevent this interposition of stray loops of bowel and also to attempt as close a correlation as possible between the two recording methods, the colon was mobilised on its vascular pedicle and inserted in the subcutaneous space, superficial to the muscle layer of the abdominal wall. The proximal colon was chosen because its myoelectrical activity correlated better with the skin electrodes than the distal colon and because it lies more anteriorly in the peritoneal cavity and mobilisation was facilitated.

Method

In four rabbits, the proximal colon was transposed to the subcutaneous tissues. Under general anaesthesia, the proximal colon was mobilised by separating planes of cleavage of the mesocolon without interfering with the blood or nerve supply. The mesocolon was incised between the arterial arcades and care was taken to preserve all vessels and nerves. The mobilised section of colon was brought out of the wound and the muscle layer was closed deep to it, leaving space at either end of the wound for the afferent and efferent limbs of the subcutaenous colon, (Figure 29). Electrodes were implanted into the taenia of the subcutaneous colon and the leads were ducted subcutaneously to exit at the base of the neck.

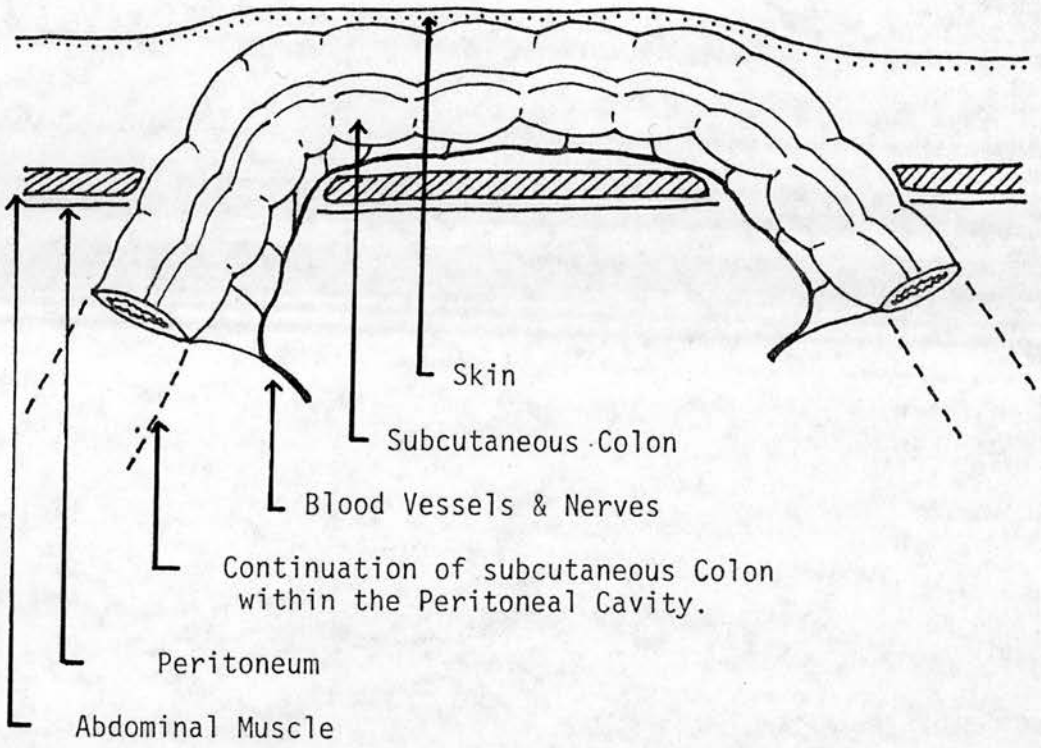


Figure 29. Diagram to illustrate the Subcutaneous Colon in longitudinal section. 10 cm of colon was mobilised without interfering with the blood supply or nerves, and transposed to the subcutaneous space. Electrodes were implanted into the taenia of the subcutaneous colon and the muscle layer was closed deep to this portion of colon. Space was left at either end of the incision to maintain continuity with the rest of the bowel.

After full recovery from the anaesthetic, twenty four to forty eight hours later, skin electrodes were attached to the abdomen in the standard bipolar longitudinal and transverse sites.

Recordings were taken from both sets of electrodes and were analysed for:

1 Correlation in frequency
2 Correlation in amplitude changes (high amplitude periods)
3 Incidence of spike potentials

At the conclusion of the experiments, immediate post mortem examination of the subcutaneous colon and peritoneal cavity was performed.

Results

Electrical activity of the subcutaneous colon.

The electrical activity detected by the electrodes implanted into the taenia of the subcutaneous colon was qualitatively different from that recorded from the colon within the peritoneal cavity, (Figure 30).

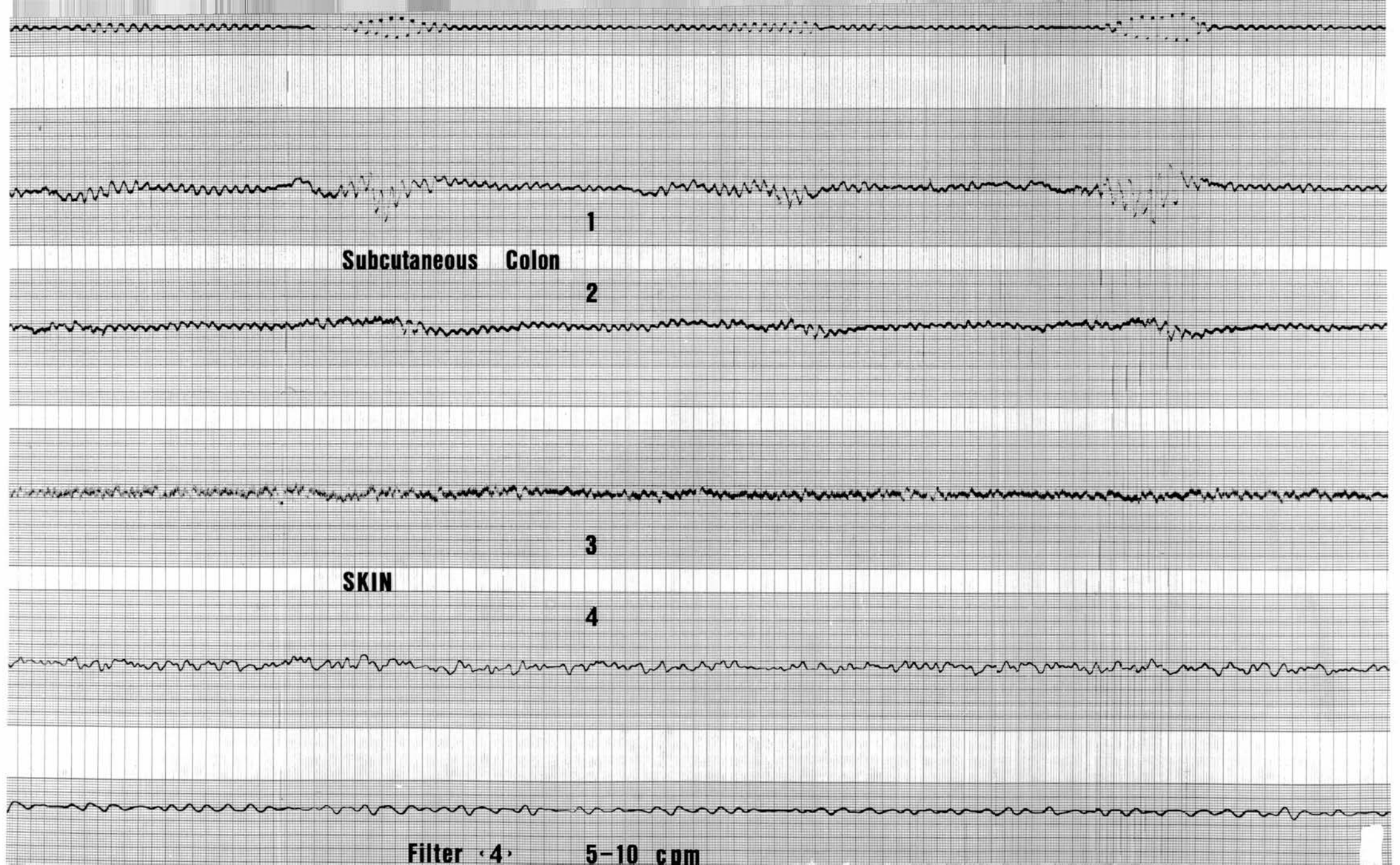
1. The slow wave was continuous and the frequency was constant - 14·5 cpm ±0·2 - 1 standard deviation, (Table 7). This contrasted with the variable frequency detected from the colon within the peritoneal cavity.

2. Changes in amplitude were detected at similar intermittent periods as previously recorded. Although the amplitude of the signal detected by the electrodes implanted into the taenia of the subcutaneous colon was increased during the high activity periods, two phenomena were observed: spike potentials were seen as continuous bursts over the full slow wave cycle and lasting 30 - 90 seconds in conjunction with the increse in amplitude. More importantly, the slow wave frequency remained unchanged during the high amplitude periods (14·5 cpm ±0·2 - 1 standard deviation - Table 7) in contrast to the increase in frequency

Figure 30

The electrical activity of the subcutaneous colon: 1 and 2 were detected by electrodes implanted into the subcutaneous colon and the uppermost trace was a filtered recording of No 1 set at 12 - 15 cpm; 3 and 4 were detected by skin electrodes and the lowermost trace was a filtered recording of No 4 set at 5 - 10 cpm.

Note the High Activity Periods in the subcutaneous colon but the absence of correlation with the activity detected by the skin electrodes.


1
Subcutaneous Colon
2
3
SKIN
4
Filter ‹4› 5-10 cpm

or frequency doubling previously recognised.

Skin Electrical potentials

Characteristic periods of increased amplitude were detected from both skin electrode pairs. The amplitude was increased and the frequency decreased during these periods.

However, there was no correlation in the high amplitude periods detected by the skin electrodes and the high amplitude periods detected by the electrodes implanted into the subcutaneous colon, whether proximal or distal colon.

Post mortem examination

Immediate examination of the subcutaneous colon and peritoneal cavity, following a lethal dose of thiopentone intravenously, showed:
1. There was no obstruction of the colon, proximal dilatation or ischaemia of the subcutaneous or intraperitoneal intestine.
2. The implanted electrodes had not been disturbed from their site of implantation and remained in situ.
3 The subcutaneous colon was surrounded by adhesions which firmly attached the colon to the subcutaneous tissues preventing gross to and fro movement.

Discussion

The correlation in detection of the colonic electrical activity could not be improved by transposing the colon closer to the skin electrodes. In fact the reverse was true in that the high amplitude period correlation ceased to exist with that part of the colon in the subcutaneous tissues.

The skin electrodes detected high amplitude periods which showed no correlation with the electrical activity of the subcutaneous colon. It is presumed, but not proven, that the skin-recorded high amplitude periods related to the colon within the peritoneal cavity.

If loops of small intestine had interposed between colon and abdominal wall, then preventing this interposition achieved nothing in augmenting the detection of myoelectrical activity by skin electrodes.

The subcutaneous colon remained healthy and functioned normally as judged by the health of the rabbit and the post mortem findings. What then was the difference between the subcutaneous colon and the intraperitoneal colon? The adhesions fixing the subcutaneous colon were an obvious difference and, while not interfering with the onward passage of luminal content, were sufficiently dense to prevent gross pendular movements of this section of colon, and in this way the gross to-and-fro movement of the colon was effectively abolished.

The implanted electrodes showed that electrical activity was present in the subcutaneous colon so it is possible that the adhesions may have an insulating effect between the subcutaneous colon and the skin electrodes. However, it is difficult to perceive how the thin layer of stranded adhesions, composed of fibroblasts, collagen and capillary loops, should prove such an efficient insulator of electrical activity.

The electrical activity of the subcutaneous colon resembles that detected in vitro, especially with respect to the slow wave i.e. a continuous slow wave with a constant frequency and the significance of this will be discussed later.

TABLE 7

The frequency of the taenia coli myoelectrical activity was calculated during the low amplitude and during the high amplitude periods of the subcutaneous colon.

The difference between the Means of the frequencies was determined and its significance.

Mean frequency during the High Amplitude Periods	14·52 cpm
Standard Deviation	0·27
Mean frequency during the Low Amplitude Periods	14·55 cpm
Standard Deviation	0·22
Standard Error of the Mean	0·352
Difference between the means	0·039
Multiple of the Standard Error of the Differences	0·096 SD
	$p < 0·5$

In the subcutaneous colon, there was no significant difference in the slow wave frequency during the high amplitude periods compared with the low amplitude periods. This is in contrast with the frequency changes recorded from the colon within the peritoneal cavity.

EXPERIMENT 7. The effect of abolishing gross to-and-fro movement of the bowel on the electrical activity detected by skin and implanted electrodes.

Contractions of the intestinal smooth muscle result in segmentation or propulsion. Simply stated, segmentation is the separation of one segment from another by a contraction of the circular muscle. In circumstances where these circular muscle contractions are synchronised, the ring of contraction is propagated orally or aborally resulting in propulsion of the intraluminal contents. By contrast, the longitudinal muscle shortens the bowel when it contracts. Contractions and relaxations of the longitudinal muscle over greater lengths results in gross to-and-fro movements of multiple segments of the bowel.

Experiment 6 suggested that gross, to-and-fro pendular movement of the colon might influence the electrical activity detected by both the implanted and skin electrodes. Experiment 7 was designed to test the effect of preventing the gross pendular movements of the intestine on the myolectrical activity detected by both recording methods. In experiment 6, only the subcutaneous colon was restricted in its gross movements. In contrast, the bowel within the peritoneal cavity remained unrestricted in its movements. Periods of increased amplitude were still detected by the skin electrodes and, as no correlation existed with the amplitude changes in the subcutaneous colon, it was considered most likely that the source for these events rested in the bowel within the peritoneal cavity, possibly the remaining colon.

Method

In four rabbits, electrodes were implanted into the taenia of the proximal and distal colon under general anaesthesia. Talcum Powder BP, 10 millilitres, were evenly distributed throughout the peritoneal cavity to ensure total and even coverage of all loops of bowel. The abdomen was closed and the rabbit allowed to recover from the anaesthetic.

After seven days, allowing adhesions to develop, recordings were taken

from the implanted electrodes and two pairs of skin electrodes at the standard sites.

The recordings from both sets of electrodes were analysed for the presence of increases in amplitude greater than twice the basal levels. A correlation in the timing of the high amplitude periods (HAP) was noted. The frequency of the waveform from both types of electrode was calculated by counting the number of cycles in 52 millimetres (1 minute).

At the conclusion of the recordings the animals were sacrificed and post mortem examination performed on the abdominal contents.

Results.

1. Skin electrodes detected respiratory movement artefact and an otherwise flat trace, (Figure 31). There were no High Amplitude Periods or significant wave form.

2. The implanted electrodes detected a continuous electrical slow wave with a constant frequency, 15 cpm, (cf Experiment 6, subcutaneous colon electrical activity). Spike potentials were detected in some recordings but only during periods of high amplitude (HAP). The frequency remained unchanged during these high amplitude periods.

Post mortem examination of the peritoneal cavity confirmed widespread adhesions between loops of bowel and the parietal peritoneum. This effectively prevented gross to-and-fro movement of the intestines without affecting the digestion, absorption and propulsion of luminal contents as witnessed by the continued health, defaecation and the lack of weight loss of the rabbits. In addition, the implanted electrodes were undisturbed from their insertion into the taenia of the colon.

Discussion

A number of observations were made in this experiment and their interrelationships determined.

a). The skin electrodes did not detect any high amplitude periods previously recognised.

b). The implanted electrodes detected a regular wave with a constant frequency, unlike previous electrical activity detected from the colon except that from the subcutaneous colon in experiment 6.
c). Adhesions were widely spread throughout the peritoneal cavity.

Two interpretations of these observations may be made:

1. The adhesions themselves might have had an insulating effect on the transmission of the electrical potential variation from the intestinal smooth muscle to the skin surface, thereby preventing their detection by the skin electrodes and in some way affecting the implanted electrode recordings.

However, there appears little in the structure of adhesions (fibroblasts, collagen and capillaries) that would provide such an effective insulation compared with the other tissues through which the electrical potentials were transmitted.

2 The rhythmic variation in electrical potential detected by the skin electrodes might be directly related to the gross movement of intestinal loops - especially the colon in the rabbit. The Talcum Powder adhesions prevented these to and fro movements and in this way may have prevented their representation in the electrical activity on the skin surface.

The talcum powder adhesions did not abolish the myoelectrical activity, which persisted throughout and was detected by the implanted electrodes. However, this recorded activity resembled the electrical activity of the smooth muscle in vitro, i.e. a continuous slow wave with a constant frequency. Spike potentials were detected and were intimately related to the high amplitude periods. The striking difference in the electrical activity was the constant frequency even during the high amplitude periods.

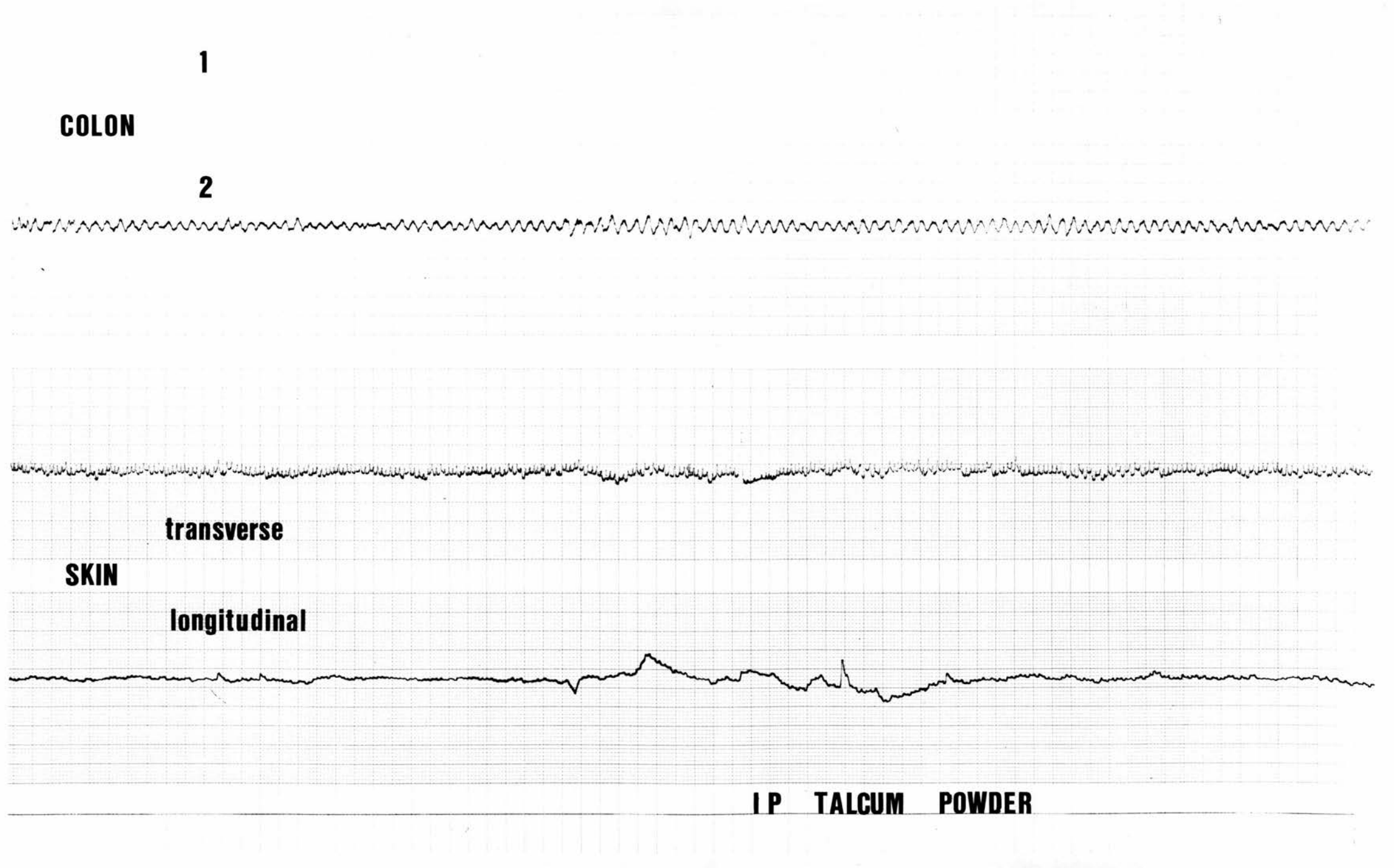
Conclusion

It would appear from these studies that restricting gross contraction movement abolished the electrical potentials detected by skin electrodes, and eliminated the factor(s) which varied the frequency of the slow wave detected by implanted electrodes.

Figure 31

The electrical activity detected by electrodes implanted into the taenia coli, 1 and 2, and skin electrodes, transverse and longitudinal, following instillation of talcum powder into the peritoneal cavity.

Note the continuous slow wave activity of the colon, the absence of High Activity Periods and the essentially flat trace from the skin electrodes.


1
COLON
2
transverse
SKIN
longitudinal
I P TALCUM POWDER

EXPERIMENT 8

Induced Electrical Potentials by Colonic manipulation

In experiments 6 and 7, the effects of abolishing gross contraction movement on the electrical activity were examined. In experiment 8, to and fro movement of the colon was artificially induced in a controlled fashion, and its effects on the electrical activity determined.

Method a)

In two rabbits, two pairs of stainless steel electrodes were implanted into the taenia of the proximal colon. A small cobalt magnet (3 x 3 x 3 millimetres) coated in silicone rubber, was attached to the serosal surface of the colon with two 3/0 silk sutures. The site of attachment was 3 cm distal to the site of electrode insertion.

Following recovery from the operation skin electrodes were attached to the standard sites and recordings taken from the implanted and skin electrodes. During the recordings, another strong magnet was held underneath the box in which the rabbit was situated. The magnet was moved firstly to and fro longitudinally below the rabbit's abdomen and secondly in a transverse direction.

This procedure was repeated while screening the position of the internal implanted magnet with a radiographic image intensifier.

Results

The electrical activity of the colon and that detected by the skin electrodes were not affected by the external movement of the magnet. The electrical activity was the same as that described in earlier experiments.

Radiographic screening of the position of the internal implanted magnet revealed that no detectable movement occurred in the internal magnet under the influence of the external magnet.

Conclusion

This method failed to produce the desired movement of the colon and consequently was abandoned.

Method b)

In four rabbits, electrodes were implanted into the taenia of the proximal colon in its mid portion. Two nylon ligatures were attached to both ends of the proximal colon, 2 - 3 centimetres from the site of electrode implantation, and the free ends of the nylon ligatures were brought to the skin surface through the abdominal wall. The laparotomy incision was closed and the nylon ligatures were coiled and taped to the skin to prevent their inadvertent removal.

Recordings from the implanted and skin electrodes were taken 24 hours later once the rabbits had fully recovered from the operation and anaesthetic. During a period of forty five minutes recording, the nylon ligatures were held in each hand and alternately pulled gently and relaxed. The ligatures were seen to move 10 - 15 millimetres each time and each manipulation lasted 10 - 20 seconds.

Results

The periods of manipulation affected the electrical activity recorded by both implanted and skin electrodes. The individual manipulations were identified by the increase in amplitude and/or change in frequency in the electrical activity detected by the skin electrodes, (Figure 32), the implanted electrodes (Figure 33) or both (Figure 34). Each manipulation was identified on each recording.

It was possible, while observing the recorded activity, to manipulate the nylon ligatures in one direction while the recording pen moved "upwards" and to increase the amplitude of the wave. In contrast, manipulations in the opposite direction while the recording pen moved "upwards" resulted in a premature down stroke and a shorter wavelength which illustrated the increase in frequency.

Discussion

The movement of the bowel by the manipulation of the nylon ligatures was a mechanical event. However, both the implanted electrodes and the skin electrodes detected an increase in amplitude when the colon was manipulated.

It could be argued that the mechanical stimulus initiated myoelectrical activity by direct stimulation and certainly, contractions may be induced by pinching the muscle wall (Bayliss and Starling, 1900). However, a single change in electrical potential followed a single mechanical manipulation and no other recognisable electrical activity was initiated from this stimulus.

In experiment 7, the skin electrical potentials were abolished when the movement of the bowel was restricted. In contrast, this experiment suggests that movement of the colon, whether by contraction or manipulation, is represented on the skin surface as a change in electrical potential.

Stainless steel electrodes have a high standing electrode potential and consequently movement artefacts are more likely than with silver/silver chloride electrodes for example. Care was taken in this experiment to site the nylon ligatures 2 - 3 centimetres from the electrodes to reduce this effect. In the next experiment, the colon is stimulated pharmacologically with neostigmine in an effort to achieve a more physiological effect on the smooth muscle.

Figure 32

The electrical activity detected by skin electrodes during manipulation of the colon by nylon ligatures attached to either end of the proximal colon. Manipulation is marked by asterisks

Note the effect of manipulation on the electrical activity.

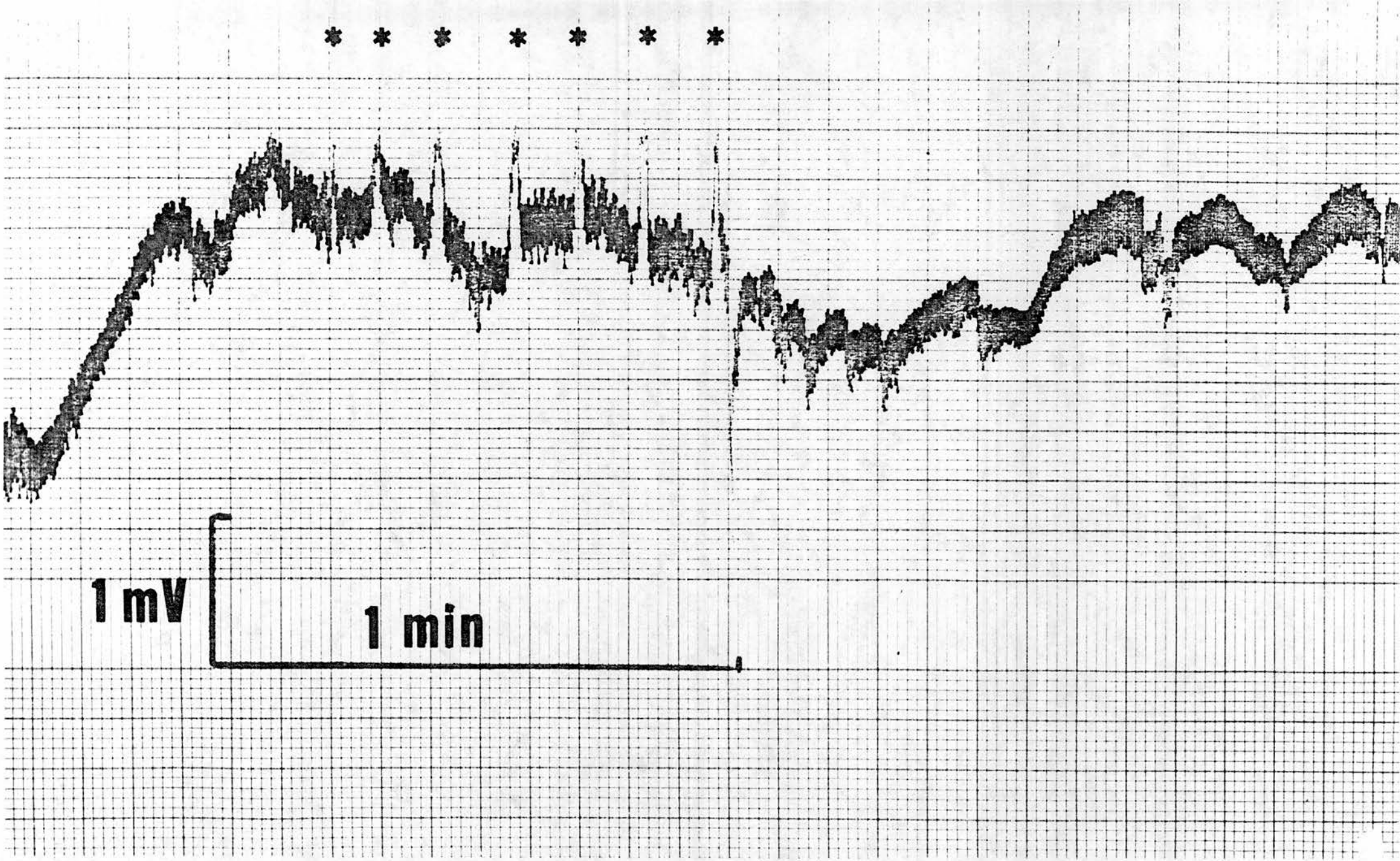

1 mV
1 min

Figure 33

The electrical activity detected by electrodes implanted into the taenia coli during a period of manipulation by nylon ligatures, marked by the broken line.

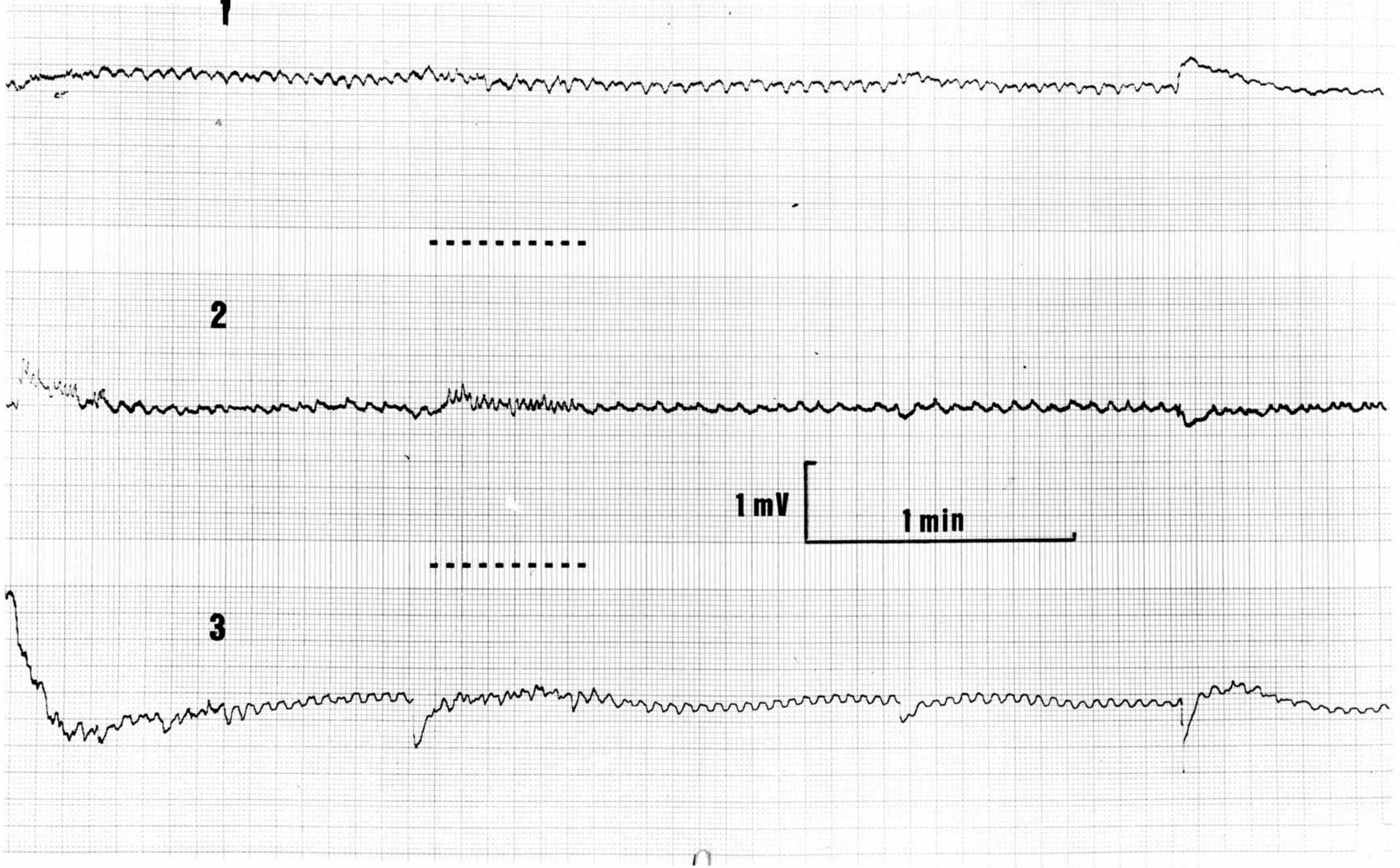
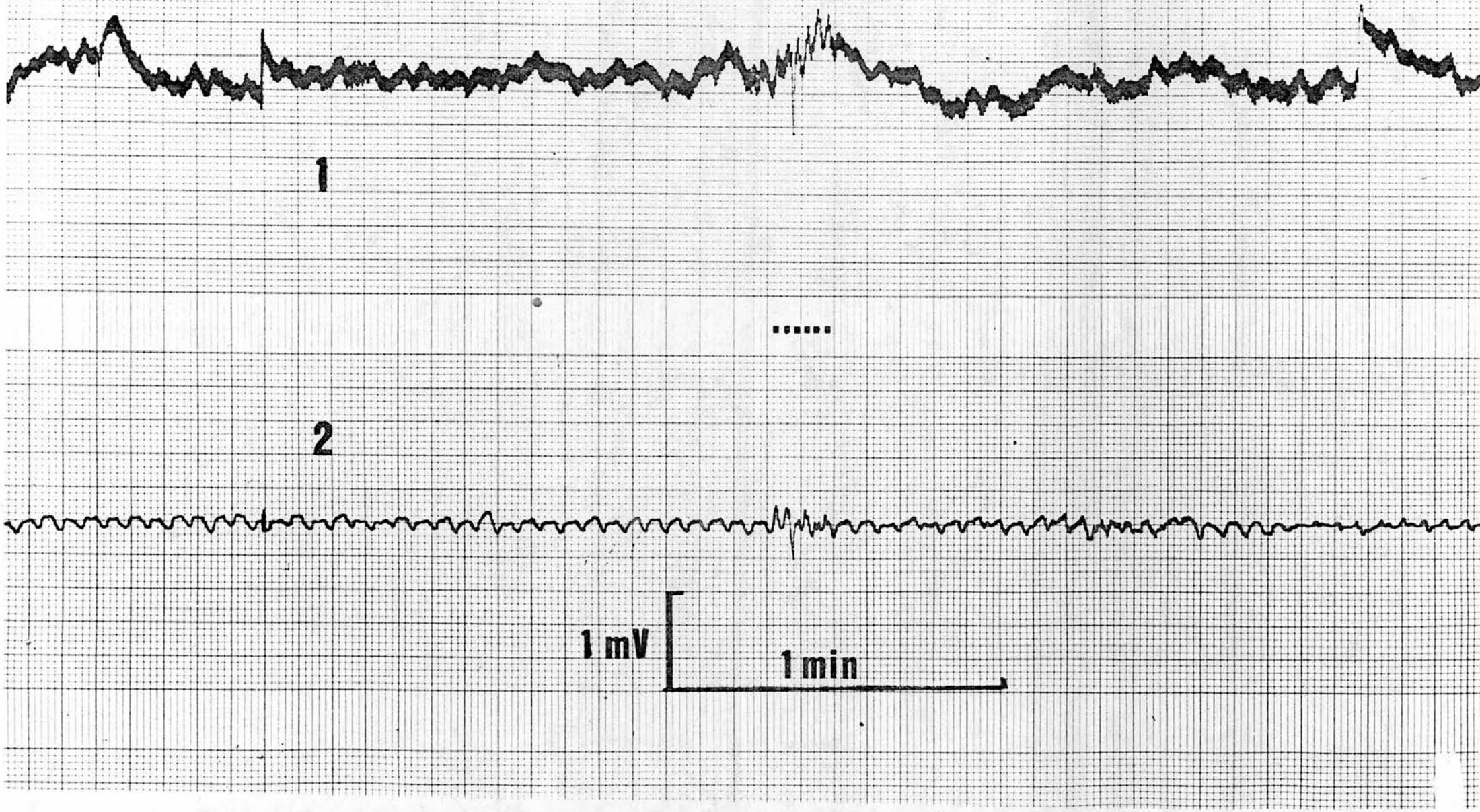

1
2
1 mV
1 min
3

Figure 34

The electrical activity detected by electrodes implanted into the colon (1) and skin electrodes (2) during a period of manipulation marked by the broken line.


1
.....
2
1 mV
1 min

EXPERIMENT 9

The effect of stimulation of the smooth muscle on the colonic myoelectrical activity.

Previous recordings in this project have been conducted in the resting state. The effect of intravenous Neostigmine on the colonic myoelectrical activity was studied in this experiment. Neostigmine potentiates the effect of acetylcholine by reversibly inhibiting the enzyme cholinesterase which breaks down acetylcholine. Acetylcholine has an excitatory effect on the motor and secretory components of the gastrointestinal tract and it would be expected to induce similar effects in one or more components of the electrical activity - the slow wave and spike potentials. Experiment 8 showed the effects of physically moving the bowel on the colonic smooth muscle electrical activity. This experiment shows the effect of moving or stimulating the bowel pharmacologically.

Method

Two pairs of electrodes were implanted into the taenia coli of seven rabbits. After full recovery from the operation, 48 hours later, bipolar skin electrodes were attached to the standard sites.

After one hour recording from both sets of electrodes, 0·15 milligrammes of Neostigmine was injected intravenously into an ear vein, over 30 - 60 seconds. A further sixty minutes recording followed.

The recordings were analysed by measuring the amplitude of the waveforms over ten minute periods before and after Neostigmine and calculating the average. This method utilises the integrator described in the General Methods section (Analysis). Statistical analysis was by Student's t Test.

Frequency analysis was performed by calculating the frequency for individual waves by counting the number of small sqares between the peaks of two full cycles and dividing by 104 (cf General Methods). In many recordings there were two frequencies present at one time and both these frequencies have been noted. These two frequencies

correspond to the frequencies detected from the colon in earlier experiments.

Results

Amplitude

A significant increase in amplitude following Neostigmine was detected by the implanted electrodes ($p < 0.001$ Table 8) and by the skin electrodes ($p < 0.01$ - Table 9).

Frequency

The predominant frequency of the slow wave, detected by both types of electrode in the basal state, remained unchanged after stimulation ($p < 0.1$ - Tables 10 and 11). However a second frequency with considerably greater amplitude detected by the implanted electrodes was superimposed on the original slow wave in three of the seven rabbits, (Figure 35).
This new waveform had a frequency of 2 - 4 cpm. The increased amplitude after stimulation was due to the presence of this second low frequency waveform.

Discussion

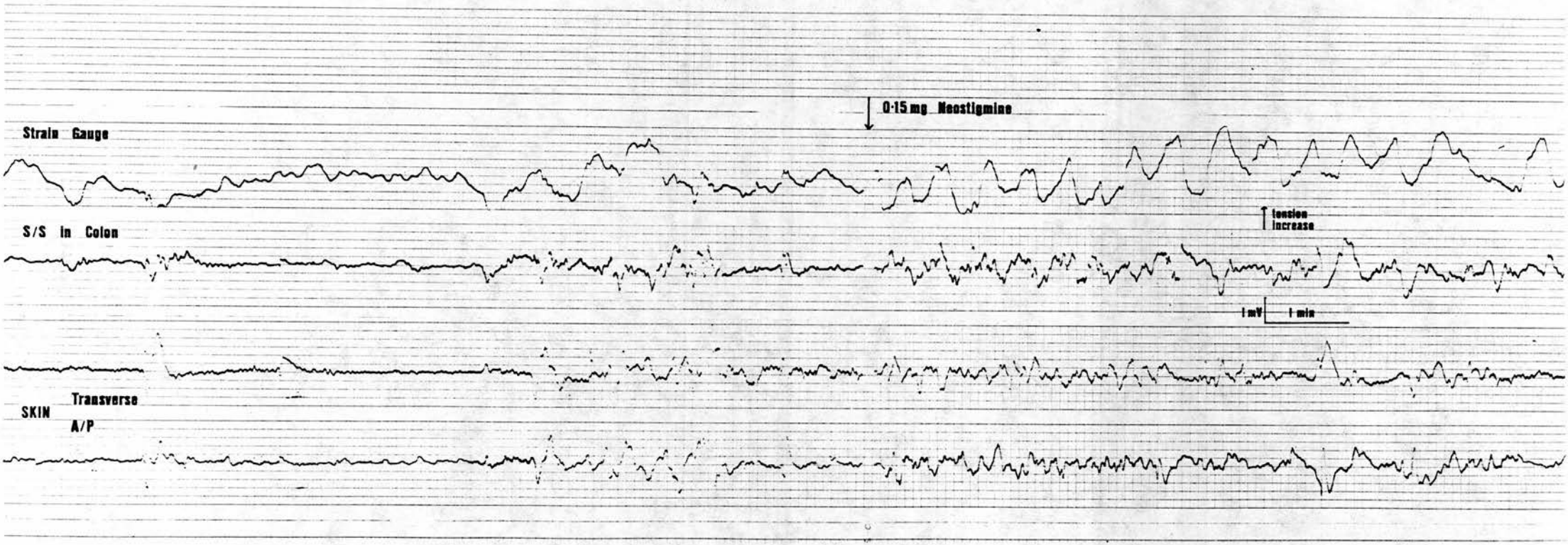
The Basic Electrical Rhythm, or slow wave, remained essentially unchanged after stimulation with Neostigmine. This observation confirms our present understanding of the electrophysiology of intestinal smooth muscle, namely that the slow wave represents the cyclical variation of the cell membrane potential and that the spike potentials initiate the contraction. By inference, one would expect the spike potentials to be increased by stimulation rather than any alteration in slow wave frequency. However, stimulation by neostigmine resulted in the development of a second wave with a lower frequency and superimposed on the original waveform. This new frequency was apparent by its high amplitude.

The source of this new frequency is difficult to determine on current physiological principles. The presence of two frequencies detected

Figure 35

The effect of Neostigmine on the motor activity (strain gauge) and electrical activity detected by electrodes implanted into the colon and skin electrodes.

Note the close correlation of motor and electrical activity of the colon together with the association of electrical activity detected by the skin electrodes.


0·15 mg Neostigmine
Strain Gauge
tension increase
S/S in Colon
1 mV
1 min
SKIN
Transverse
A/P

from the same point in the colonic muscle might suggest the presence of two separate 'pacemakers'. However it would be necessary to postulate an insensitivity of one bundle of muscle fibres to another set of muscle cells whose membranes were depolarising at the slower rate. Without this insensitivity, the cells working at the faster rate would drive the second set of cells resulting in an increase in frequency and thereby cancelling out the difference in the two frequencies.

The lower frequency with the high amplitude has been observed already in earlier recordings. This has been recognised as the high amplitude periods during which the amplitude increased and the frequency altered. Possibly of relevance is the observation that spike potentials, in earlier recordings in the resting state, were detected only during the high amplitude periods and these periods have been thought to represent periods of motor activity.

Few of the recordings detected spike potentials in the basal state but after stimulation, a continuous discharge of spike potentials was observed in two recordings. Most of the rabbits defaecated after stimulation and these two facts suggest that the motor activity was increased.

Increased motor activity implies increased contraction movement and, on the basis of experiments 7 and 8, an increase in amplitude of electrical activity would be anticipated in the skin and colon electrode recordings. This was indeed so and supports the premise that contraction movement may be represented as change in amplitude of the electrical potential detected by the skin electrodes.

TABLE 8

Change in amplitude of electrical activity detected by electrodes implanted into the taenia coli in the rabbit.
The average amplitude over ten minute periods were measured in millimetres, (1mV = 15mm), before and after Neostigmine.

Stimulation by 0·15 milligrammes Neostigmine intravenously.

Twelve recordings in seven rabbits.

Basal Amplitude	Stimulated Amplitude	
20	54	
14	36	
3	17	
23	53	
14	25	n = 12
16	56	d = 21·25
22	40	Ed = 255
3	3	$(Ed)^2$ = 65025
14	60	Ed^2 = 7714
25	31	
23	30	
18	45	

$t = 5·1$

$p < 0·001$

There was a highly significant increase in amplitude after stimulation with Neostigmine.

TABLE 9

Change in amplitude of electrical activity detected by skin electrodes on the rabbit abdomen.
The average amplitude over a ten minute period was measured in millimetres (1mV = 15 mm).

Stimulation by 0·15 milligrammes Neostigmine intravenously.

Seven recordings in seven rabbits.

Basal Amplitude	Stimulated Amplitude	
10	16	
33	52	n = 7
22	45	d = 13·86
25	39	Ed = 90
28	30	$(Ed)^2$ = 8100
27	40	Ed^2 = 1464
12	25	

$t = 5 \cdot 13$

$p < 0 \cdot 01$

Skin electrodes detected a significant increase in amplitude after stimulation with Neostigmine.

TABLE 10

Change in frequency of the electrical activity detected by skin electrodes on the rabbit abdomen.

Where two frequency ranges existed, the average within each frequency was noted (cf frequency change during high amplitude periods) and these were paired with the frequencies detected after stimulation with Neostigmine, 0·15 milligrammes intravenously.

There were thirteen recordings in seven rabbits.

Basal Frequency (cpm)	Stimulated Frequency (cpm)	
6·4(5·7)	6·4(5·4)	
6·4(6·4)	5·7(6·4)	
5·7(4·5)	5·7(4·5)	
17(8·5)	17(7·3)	Bracketed numerals
21(10)	-(8·5)	indicate the frequency
9·7(8·5)	21(11)	during the HAP.
14	21	
7·3(14)	8·5(16)	
17(4·1)	17(5·7)	
21(4·2)	17(4·6)	
19(10)	20(8·5)	
21(6·4)	21(5)	

$$t = 1{\cdot}579$$

$$0{\cdot}5 > p > 0{\cdot}1$$

There was no significant difference in frequency detected by skin electrodes, before and after stimulation.

TABLE 11 Change in frequency of the electrical activity detected by electrodes implanted into the taenia coli of the rabbit.
Where two frequency ranges existed, the average within each frequency range was noted (cf frequency change during high amplitude period). The basal recorded frequency was paired with the frequency detected after stimulation with Neostigmine 0.15 milligrammes intravenously.

There were nineteen recordings with seven rabbits.

Basal Frequency (cpm)	Stimulated Frequency (cpm)	
15	15	
10	8	
7	9	
16(6·4)	16(10)	Bracketed numerals
7·3(16)	9(21)	indicate the frequency
5·7(18)	9(18)	during the HAP.
15	10	
12	7	
21(10)	-(10)	
17(6·8)	21(8·5)	
21(6·4)	26(7)	
14	13	
15	15	
3·2	2	
13	11	
6·4	3·4	
17	17	
6·8	2·7	

$t = 0{\cdot}69$

$0{\cdot}5 > p > 0{\cdot}1$

There was no significant difference in frequency detected by implanted electrodes before and after stimulation.

EXPERIMENT 10

The relationship of Motor and Electrical Activity

In vitro experiments of smooth muscle preparations have revealed the relationship between the slow waves, spike potentials and the muscular contraction. In vivo, the electrical activity appears more complex and the slow wave had a higher frequency. It has been assumed that the multiple factors: neural, humoral and physical, being exerted in vivo, were, in part, the reason for this difference. Experiments 6, 7 and 8 suggest that the physical movement of loops of bowel during contractions affected the electrical activity detected by the implanted electrodes and was instrumental in producing the fluctuation in electrical potential detected by the skin electrodes.

However, although there was good presumptive evidence for the presence of contractions in the earlier experiments, these contractions were not recorded and have not been measured directly.

It was the aim of this experiment to study the electrical activity of the taenia coli and at the same time record the contractions that were produced. Special reference was made to the significance of the high amplitude, low frequency electrical rhythm detected by the implanted electrodes after stimulation of the colon with neostigmine.

Method

In eight rabbits, encapsulated strain gauges were attached transversely to the proximal and distal colon at two sites. A pair of electrodes was implanted into the taenia at either side of the strain gauge to detect the electrical activity at the site of the recorded motor activity (Figure 11 General Methods). In this configuration, the strain gauges detected changes in curvature (as a function of the diameter) of the colon.

Forty eight hours later, following full recovery from the operation, recordings were taken from both the implanted electrodes and strain gauges for sixty minutes. 0.15 milligrammes Neostigmine was injected intravenously and a further sixty minutes recording followed.

The recordings were analysed for frequency and amplitude in both electrical and motor activity and the two sets of recordings were compared.

Results

Basal Recordings

Electrical Activity

In the resting state, the electrical activity recorded by the implanted electrodes, showed a low amplitude regular waveform with a constant frequency, 14-17 cpm (Figure 36). This was very similar to that recorded from the subcutaneous colon, in experiment 6 and the higher frequency in the other colon myoelectrical recordings.

Motor Activity

The strain gauges detected motor activity consisting of a continuous series of contractons occurring with the same frequency as the electrical slow wave.

Stimulation Recordings

Electrical Activity

Following stimulation with neostigmine, the 14 - 17 cpm electrical slow wave frequency persisted unchanged, but this was superimposed on a high amplitude (2 - 3 mV) low frequency (2 - 4 cpm) waveform identical to the stimulation-induced electrical wave detected in experiment 9.

Motor Activity

The strain gauges detected contractions of the colon which very closely resembled the waveforms detected by the implanted electrodes. The lower amplitude higher frequency (14 - 17 cmp) contractions were superimposed on much higher amplitude, low frequency (2 - 4 cpm) contractions after stimulation with neostigmine. The peaks of the stimulation-induced high amplitude electrical wave coincided with the

peaks of the high amplitude contractions (Figures 35 and 36), demonstrating a very good correlation between the motor and electrical recordings (83% correlation for the low frequency, high amplitude waves and 95-98% for the higher frequency, low amplitude waves).

Discussion.

The electrical activity detected by the implanted electrodes was intimately related to the motor activity as detected by the strain gauges. There were two phenomena demonstrated by this experiment:

1) In the basal, resting state the frequency of the electrical slow wave showed a good correlation with the rate of the low amplitude contractions, in a 1:1 relationship (quantitative analysis adds little more to this observation). Classical teaching suggests that the electrical activity initiates the contraction and, although no spike potentials were observed in these recordings, these results would support our present understanding of smooth muscle electrophysiology.

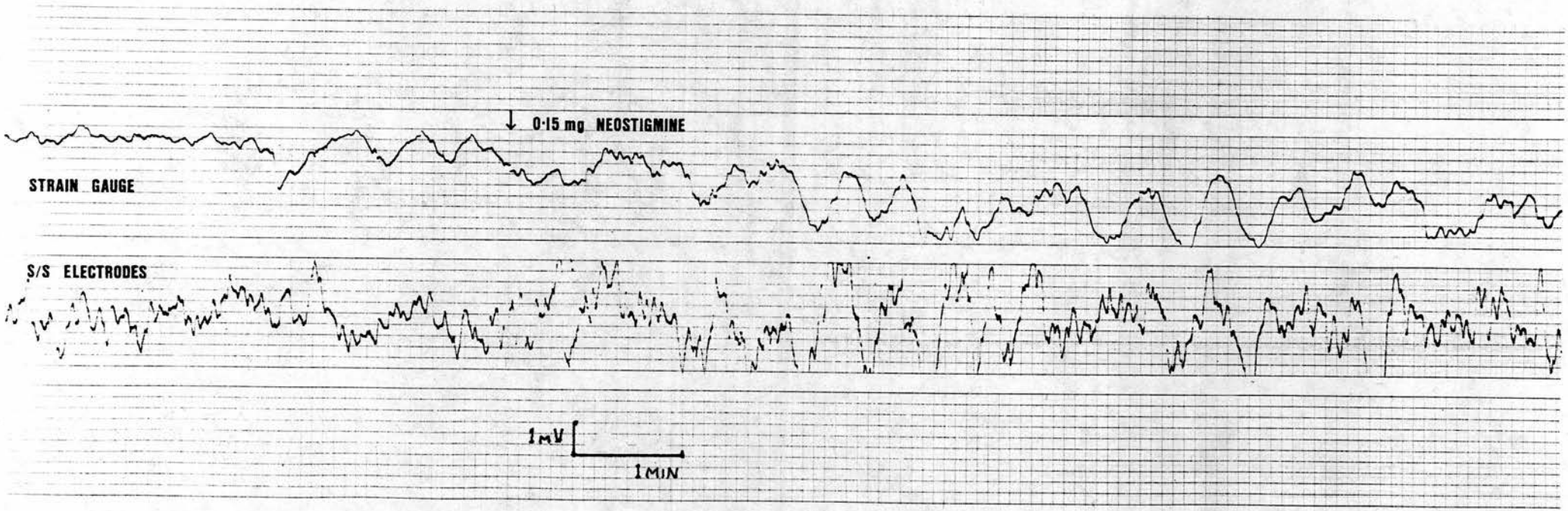
2) After stimulation, a new waveform was detected in both the electrical and motor recordings. The strain gauges were very sensitive to change in stress and strain which included change in curvature of the gauge. They were also sensitive to temperature changes but being in an homeostatic environment this had minimal relevance. Hence, the strain gauge detected local mechanical activity only, whereas the electrodes, in detecting electrical activity of the smooth muscle cells, might also be influenced by local contractions disturbing the electrodes at the site of implantation.

The stimulation-induced, high amplitude electrical wave might originate in a second loosely-coupled smooth muscle oscillator but in view of its close association with the motor wave the stimulation-induced electrical wave is more likely a contraction movement artefact.

Figure 36

The effect of Neostigmine on the motor activity (strain gauges) and electrical activity detected by implanted electrodes is illustrated.

Note the increase in amplitude of the motor and electrical recordings together with the initiation of a high amplitude low frequency motor and electrical wave and the close correlation between the two recordings.


↓ 0·15 mg NEOSTIGMINE
STRAIN GAUGE
S/S ELECTRODES
1mV
1MIN

SUMMARY

Skin Electrode Recordings

The characteristic electrical activity of the rabbit taenia coli with its High Amplitude Periods was identified in experiment 1. Electrical potentials were recorded from the abdominal skin and this was uninfluenced both by the type of electrode or method of attachment suggesting that this activity was not generated at the skin/electrode interface, i.e. it was not an electrode artefact.

Experimentation of skin electrode sites around the body revealed that it was essential for the abdomen to be situated between the electrodes for the recording of electrical potential variations such as those previously described. Experiment 4 showed that the high amplitude periods detected by electrodes implanted into the colon was also detected by the skin electrodes although there was no correlation in frequency. Paradoxically, where the frequency increased during the high amplitude periods detected by the implanted electrodes, the frequency decreased during the high amplitude periods detected by the skin electrodes.

The excision experiments confirmed that the skin electrodes detected activity originating in the colon. However, recordings with the subcutaneous colon revealed an unexpected pattern of activity which took nine months to comprehend. Up to this stage, the skin electrodes appeared to detect activity which, in the rabbit, correlated well with the colon electrical activity and would support other published work using skin electrodes (Alvarez, 1922; Martin, 1969; Duthie, 1975; Taylor, 1975; Brown 1975; Smout, 1980). Although the skin electrodes detected the high amplitude periods there was no correlation with the high amplitude periods in the subcutaneous colon and presumably the skin high amplitude periods originated from the colon within the peritoneal cavity.

Preventing all gross movement with intraperitoneal talcum powder, removed all traces of electrical activity from the skin electrode recordings and manipulation of the colon produced electrical potential changes which were detected by the skin electrodes and implanted electrodes.

It is clear that the skin electrodes were detecting movement of the bowel within the peritoneal cavity and especially movement of the colon. This movement was due to contraction of the colonic muscle which was revealed by the strain gauge studies. The (apparent) association with the myoelectrical activity of the colon detected by implanted electrodes was due to the close relationship of electrical to motor activity previously described.

In diagramatic form, Event A (the slow wave and spike potentials) give rise to Event B (the contractions) which results in Event C (the to-and-fro movements of the bowel). These events are closely interrelated and previous studies (Alvarez, 1922; Martin, 1969; Duthie, 1975; Taylor, 1975; Brown 1975; Smout, 1980) using skin electrodes have suggested that this method detects the electrical activity of the intestinal smooth muscle. However, this study has shown that the implanted electrodes detected Event A; the strain gauges detected Event B; and the skin electrodes detected Event C. The postulated mechanism involved would behave thus: the smooth muscle membrane becomes depolarized and enters the spike zone whereupon spike potentials are initiated. The spike potentials trigger contractions of the smooth muscle, both circular and longitudinal which, in combination with other contracting segments, move the loop of colon to and fro in a pendular fashion. The implanted electrodes detect the change in electrical potential between the two tips, one centimetre apart, which is composed of the myoelectrical activity of the smooth muscle in that area. In contrast, the skin electrodes detect the movement of the colon due to the contractions.

It is postulated that the loop of colon has a standing electrical potential producing an electrical field and the movement of this electrical field between the skin electrodes results in a change in electrical potential being detected by the skin electrodes. By abolishing all gross movement, the myoelectrical activity persists but the skin electrical potentials disappear. Increasing the contraction movement, with Neostigmine, demonstrated by the strain gauges, also increased the amplitude of the recorded skin electrical potentials and there was a 1:1 correlation between the two recordings.

Alvarez, 1922, observed that his very thin elderly female patient had

antral contractions visible through the abdominal wall and these contracton events coincided with his skin electrode recordings.

Brown et al 1975 described an increase in amplitude in the skin electrical recordings following a meal and suggested that this was due to the distended stomach lying closer to the electrodes. A meal is a powerful stimulus for an increase in the contractions of the stomach.

Smout et al, 1980, claimed that the electrical activity detected by skin electrodes attached to the abdomen of dogs (Event C), was due to the summation of slow waves and spike potentials, (Event A). Simultaneous contractions were revealed by implanted strain gauges, (Event B) -(author's parentheses).

In light of this present work, it is apparent that a modified interpretation of these events be made.

THE SKIN ELECTRODES DETECT CONTRACTION MOVEMENT RATHER THAN TRUE MYOELECTRICAL ACTIVITY.

Implanted Electrode Recordings

Initial recordings with electrodes implanted into the taenia coli in the rabbit revealed a slow wave frequency which increased during the high amplitude periods. In the proximal colon the frequency doubled during the high amplitude periods.

In contrast, the myoelectrical activity of the subcutaenous colon exhibited a slow wave with constant frequency and high amplitude periods during which spike potentials were recorded. Spike potentials were never observed outside the high amplitude periods. The same electrical activity was recorded from the colon within the peritoneal cavity following instillation of talcum powder, which had the added effect of preventing the gross to-and-fro movements of the bowel.

Whereas preventing bowel movement abolished the skin electrical activity, in contrast the myoelectrical activity of the colon persisted, albeit in a modified form. It would appear that bowel movement and/or movement of the electrodes at the site of implantation produced changes in electrical potential which were superimposed upon the recorded myoelectrical activity.

At the site of implantation the electrodes were surrounded by an electrolyte solution - the extracellular fluid, and changes in electrical potential between two identical electrodes were recorded. The change in potential was due to the change in local concentration of ions with respect to the concentration of ions at the opposite electrode. Movement of the electrode or the bowel with respect to the electrode disturbs the ion pool surrounding the electrode resulting in a change in local concentration. This would be registered as a change in electrical potential. Rapid transient disturbance of the electrode would be recorded as a transient change in potential and a rapid "flick" of the recording pen.

However, a more prolonged and gentle disturbance, by the muscular contraction itself, would be represented by a similar gradual change in potential and a wave-like deflection of the pen recorder.

In the peritoneal cavity with the bowel free to move, contractions would tend to produce an electrical artefact due to the disturbance of

the electrode. This contraction movement artefact together with the myoelectrical slow wave might produce an increase in amplitude and an increase in frequency. This is otherwise recognised as the High Amplitude Period.

Although these experiments have been conducted in one animal species, the electrodes and methods are similar to, and in many instances more sensitive than those employed in other animals and in human studies. It should be appreciated that contraction movement can produce electrical artefacts whose waveform resembles that of the contraction. This has been demonstrated by the strain gauges in experiment 10.

In human colon motility studies, electrical slow waves and pressure waves at 3 cpm have been recorded together with electrical activity at a higher frequency, (Taylor, 1974). The 3 cpm electrical activity has a greater predominance in the Irritable Bowel Syndrome which is recognised as a condition associated with increased motility (i.e. contractions).

This present study suggests that the 3 cpm electrical activity might be a contraction movement artefact which would be expected to be more common in a condition such as the Irritable Bowel Syndrome where the contractions are increased.

The use of skin electrodes in human subjects to record the myoelectrical activity of the gastrointestinal tract would be unrewarding and inappropriate, in view of the conclusions of these experiments. However, the strain gauges were appealing in their simplicity and with a different design, contractions could be detected from the lumen of the bowel which meant that implantation and retrieval were no longer a problem. This new application was found to be more appropriate in human subjects and was used in Section 2.

S E C T I O N 2

MOTOR ACTIVITY OF THE HUMAN COLON

Motor Activity of the Colon with Special Reference to the Irritable Bowel Syndrome.

Introduction

The original proposal of studying the myoelectrical activity of the human intestinal smooth muscle by using skin electrodes was abandonned in view of the conclusions of Section 1. In addition, the implanted electrodes were considered unreliable as an investigative technique in view of the contraction movement artefact. On consideration, a method which recorded one parameter and was little affected by artefacts would be preferable. For this reason studies of the motor activity of the human colon were performed using strain gauges.

Contractions of the Colon

"Motor activity" implies the effect of contractions of the intestinal smooth muscle, both longitudinal and circular. The contractions, coordinated by the instrinsic nerve supply, have specific actions such as mixing and propelling luminal contents.

Segmental contractions

Strong contractions of a series of circular muscle fibres divide the intestinal lumen into separate segments, hence the term "segmental contractions". Segmentation is the predominant motor activity of the distal colon especially in the sigmoid colon, (Ritchie, 1968).

Propulsive contractions

Where there is a spreading wave of contractions along the bowel, the luminal contents may be propelled from one segment to another, (Ritchie et al, 1962). These propelling waves of contraction in the colon are called "propulsive" where the direction of spread is toward the anus and "retropulsive" where the direction is towards the mouth, (Ritchie, 1968). In the proximal colon, retropulsion appears to be the predominant form of motor activity, (Cannon, 1902). This starts near mid Transverse colon, spreads towards the caecum and aids mixing

and absorption of water from the semiliquid faeces.

Peristalsis

"Peristalsis" is the type of propelling contraction where a wave of dilatation precedes the spreading ring of contraction. In the colon, peristalsis was observed once in more than two hundred periods of cineradiographic and pressure recording, (Ritchie et al, 1962).

Mass movement.

Segmentation slows transit of faeces until the onset of a propulsive wave. This propulsive wave may start in the proximal colon and result in the rapid delivery of faeces into the distal colon and rectum. This transport of a large quantity of stool is called a "Mass Movement" and may occur only once or twice a day, (Holznecht, 1909; Williams, 1967; Holdstock et al, 1970).

Disorders of Colonic Function

The colon would appear to be a relatively simple organ and alteration of its motor activity has direct consequences on its function.

Diarrhoea and Constipation

It was previously suspected that increased motor activity of the colon resulted in rapid transit and hence diarrhoea, and conversely, diminised motor activity retarded transit and resulted in constipation. In 1961, Connell studied the intraluminal pressure waves of patients suffering from diarrhoea or constipation. He discovered that the colon motor activity was the reverse to that expected. Patients with diarrhoea had very few pressure waves and those with constipation had particularly strong pressure waves. Although this is a simple view of the situation, this is consistent with our present understanding of colon motor activity where an increase in segmentation results in a reduced rate of transit and hence constipation, and conversely a decrease in segmentation results in a rapid transit of stool, less time to absorb water and

consequently diarrhoea.

Pain

The intestinal smooth muscle is pain sensitive to two stimuli: distension and ischaemia. Stretching of the smooth muscle occurs when the bowel becomes distended which might occur proximal to an obstruction. Abdominal pain and distension are common complaints of patients suffering from constipation and the Irritable Bowel Syndrome (IBS). In these two conditions it is reasonable to suppose that the bowel proximal to the faecal loading in constipation or the increased muscular contractions in the IBS, becomes distended and painful.

In view of the arrangement of the nerve supply to the fore- mid- and hindgut, visceral pain is appreciated as a dull, pain in the midline, either epigastrium, umbilicus or hypogastrium. However, many patients with the IBS localise their pain to one side of the abdomen or the other and this is often related to a tender, palpable segment of bowel, usually colon. There would appear to be more than one mechanism of pain production in the Irritable Bowel Syndrome.

The IRRITABLE BOWEL SYNDROME (IBS)

Synonyms: Irritable colon syndrome; Spastic colon; mucous colitis.

Definition

The (IBS) is a common chronic relapsing condition of unknown aetiology affecting the gastrointestinal tract and characterised by abdominal pain and alteration of bowel habit. Manning et al took detailed histories from new patients attending gastroenterolgical and surgical clinics and reviewed the diagnoses many months later. They found the following symptoms to be associated to the IBS in a statistically significant degree:

1. Loose stools at the onset of pain
2. More frequent bowel motions at the onset of pain
3. Pain eased after bowel motions
4. Visible distension

5. Mucus passed per rectum
6. Incomplete evacuation

History

Ryle, 1928 attributes John Howship, 1830 as being first to describe the clinical features of spastic colon although this reference has been impossible to review. Cumming in 1849 gave a good description of a "peculiar affectation of the mucous membrane of the bowels" and advised avoiding aperients, local heat and electrogalvanism in its treatment.

Incidence

The IBS is a common condition, Kirsner and Palmer, 1958 estimate 50 - 70% of all patients with gastrointestinal complaints suffer from the IBS, while Ferguson et al estimate 26% of patients attending the gastroenterological outpatients department suffer from the IBS.

Classification

Chaudhary and Truelove, 1962, documented 130 cases of the IBS and described two separate groups: spastic colon group and the painless diarrhoea group. The spastic colon group suffered from abdominal pain and periodic constipation or diarrhoea or both.

There have been a number of attempts to subdivide the IBS. Chaudhary and Truelove's original classification has not been adhered to in the majority of studies which followed. Champion, 1975, claimed that painless diarrhoea was uncommon, Waller and Misiewicz, 1969, included painless diarrhoea as part of the IBS but gave no indication of the numbers involved. Goulston, 1972, gave priority to the presenting symptom when dividing his IBS classification: those with pain were categorised as "spastic colon" and those with diarrhoea with or without pain were described as "nervous diarrhoea". Connell, 1968, suggests that the painless diarrhoea is a distinct condition and must be distinguished from the irritable colon (pain and alteration of bowel habit). Most workers appear to agree and recent studies in the

IBS have not included painless diarrhoea in their classification (Taylor, 1978, Snape, 1976)

Sex Ratio

Females were twice as commonly affected as males and in many series more so, (Cumming, 1849; Ryle, 1928; Chaudhary and Truelove, 1962; Waller and Misiewicz, 1969; Goulston, 1972).

Age of onset

The above references illustrate the young age of onset, under 45 years, and Waller and Misiewicz suggest a link with childhood IBS.

Clinical Features

Food and meals

The abdominal pain may occur shortly after meals (Lumsden et al, 1963). Chaudhary and Truelove, 1962, found in eight of their 130 patients that any meal aggravated their symptoms while 54 were exacerbated by particular foods. This sensitivity to particular foods has been recognised by Kirsner and Palmer, 1958, and Goulston, 1972.

Menstruation

Ryle, 1928, and Goulston, 1972, have reported that the pain of some of their female patients was worse around the time of menstruation.

Psychological Factors

The importance of psychological factors in the possible aetiology of the IBS has been reported by many, (Cumming, 1849; Ryle, 1928; Kirsner and Palmer, 1958; Chaudhary and Truelove, 1962; Lumsden et al, 1963; Waller and Misiewicz, 1969). Laboratory studies have shown that discussion of emotional topics increased colonic intraluminal pressure wave activity (Almy et al, 1949; Chaudhary and Truelove, 1961). It is worth noting that emotional topics proved a potent stimulus to colonic pressure in a normal control group and in an ulcerative colitis group (Chaudhary and Truelove, 1961).

Purgatives

Purgatives have been misused for centuries. Cumming, 1848, and Ryle, 1928, noted the frequency of purgative abuse in their patients. More recently, Kirsner and Palmer, 1958, Chaudhary and Truelove, 1962 and Lumsden et al, 1963, recognised the frequent abuse of purgatives although no mention was made of the prevalence of purgative use in the general population at the time or of a control group.

Anthroquinone purgatives stimulate the myenteric plexus (Bennett, 1975) and after chronic dosage the colonic muscle is unable to respond to physiological stimuli. In order for the colon to empty, the "cathartic colon" requires a further stimulation with the purgative. It is possible that damage or interference with the intrinsic nervous system is perpetrated (Smith B, 1968).

Dysentery

A significant number of IBS patients have a past history of "dysentery" and the symptoms persist despite repeated therapy and negative stool cultures, (Ryle, 1928; Chaudhary and Truelove, 1962; Lumsden et al, 1963; Connell, 1964). Vibrio cholera produces an alpha toxin which paralyses the myenteric plexus as well as interfering with active absorption of salt and water. This results in profuse diarrhoea. A similar effect may play a part in the IBS, disturbing the

balance of control between stimulation/inhibition in the neural and humoral regulation of the intestinal smooth muscle.

Previous operations

Acute exacerbations of the IBS have mimicked other more serious conditions for which many laparotomies have been performed, (Waller and Misiewicz, 1969; Goulston, 1972). Ryle 1928, noted that 36% had had a previous appendicectomy and Chaudhary and Truelove, 1962, showed that a third of males had had an appendicectomy and a third of the females had had an appendicectomy or gynaecological operation. They reviewed the pathology reports of the excised specimens and most appendices were normal.

Physical examination

On physical examination, patients with the IBS are in general in good or excellent health (Chaudhary and Truelove, 1962) and the scars of previously mentioned operations frequently noted (Goulston, 1972; Ryle, 1928). Palpation of the abdomen revealed tenderness over the colon (Chaudhary and Truelove, 1962) and spasm of the colon may be palpated in part or all of the colon, (Ryle 1928; Kirsner and Palmer, 1958).

Site and Character of the Pain

The pain was felt over the course of the colon and most frequently in the left iliac fossa (Cumming 1849; Ryle 1928; Chaudhary and Truelove, 1962; Goulston, 1972). The pain varied in severity and may be colicky or continuous (Chaudhary and Truelove, 1962; Goulston, 1972).

Radiological findings in the IBS

Lumsden et al 1963 performed barium enemas in patients with the IBS and was able to observe that the lumen was small and the barium failed to flow readily around the colon due to the spasm of the colonic muscle. Abdominal discomfort was frequently experienced or even pain and the desire to defaecate.

Prognosis

Waller and Misiewicz, 1969, showed that the IBS is a chronic relapsing condition which is liable to recur with repetition of the presenting symptom(s).
Prognosis in the post-dysenteric group appears to be better (Chaudhary and Truelove, 1962).

Treatment

The beneficial effect of the follow-up visits was observed by Waller and Misiewicz, 1969.

Antispasmodics

Antispasmodics are frequently used (Ritchie and Truelove,1979). Atropine, Propantheline or Hyoscine work effectively and rapidly when given intravenously but are short acting and the side effects are unpleasant: dry mouth, blurred vision. Antispasmodics with a longer action and fewer side effects eg Mebeverine have been widely used but good evidence of their effectiveness is poor. Recently, enteric coated peppermint oil has been advocated to relax the smooth muscle, especially the ileum (Rees et al, 1979).
Diet

Specific aggravating foods should be avoided but otherwise little restriction is necessary. Bulking agents such as Ispaghula (Isogel), Sterculia (Normacol Special) and Methyl cellulose (Celevac) are effective in softening the stool provided adequate fluid is included in the diet. Bran has been shown to decrease intraluminal pressure in the colon in patients with Diverticular Disease but is conraindicated in the IBS due to its bloating and flatulent effect.

Bolin, 1980, studied 20 patients with painless diarrhoea and gave then oral sodium cromoglycate. Eight patients showed a significant improvement suggesting that an ingested allergen might be responsible directly or indirectly in this 40%. This study however was

uncontrolled.

Sedatives and Antidepressants

Tranquillizers are indicated in those patients where anxiety is a predominant feature though care must be exercised in those patients wishing to drive or operate machinery.

Tricyclic antidepressants have atropine-like side effects which may have a peripheral effect on the intestinal smooth muscle in addition to its central action on the nervous system.

Psychological factors in the IBS

To what extent does the mental state of the patient influence the function of his bowels? Most authors have commented on the psychological state of the patient with IBS (Cumming 1849; Ryle 1928; Kirsner and Palmer 1958; Chaudhary and Truelove 1962; Lumsden et al 1963; Waller and Misiewicz 1969). Anxiety, depression, overconscientiousness, sensitivity, dependence, guilt, rigidity, obsessions, marital-, parental- or sexual difficulties and phobias have all been documented.

It remains unclear, however, what precise relationship these psychological factors have with the IBS. If IBS symptoms occur in the general population, whether or not related to stressful circumstances or meals, these sufferers as a rule do not seek medical attention. Wyman et al, 1978, showed that the bowel habit in normal subjects varied appreciably in stool weight, consistency and frequency although none complained of abdominal pain. The question that must be asked is: 'What makes a patient, a patient?' Perhaps, 'When he complains'. The act of complaining may select a proportion of the population who have the symptoms referable to the IBS and the introspective personality which concentrates their attention on their abdominal symptoms. Whitehead et al, 1982, showed that patients with the IBS had more somatic complaints than a peptic ulcer group or a controlled group. They suggest that chronic illness behaviour may be learnt in childhood. This is a broad generalisation and does not diminish the

severity of the symptoms.

Objective psychological tests on the two groups showed the IBS scored highly on somatization of affect, anxiety, interpersonal sensitivity, depression and hostility but not on obsessive-compulsive activity.

We already know that the mental state of normals influences the motor activity of the colon (Chaudhary and Turelove, 1962) and this is probably mediated through the autonomic nervous system. Neostigmine increases motor activity and this would implicate the parasympathetic system. However, in the search for the mechanism of the gastrocolic reflex, gastrin and cholecystokinin increase motor and electrical activity of the colon (Snape 1978) and cholecystokinin is one of many alimentary peptide hormones which is found in the central nervous system and a humoral link may exist in this way between the central nervous system and the intestine, (Besterman et al, 1981).

Electrical Activity in the Irritable Bowel Syndrome

In vitro Electrical Activity

In vitro studies of the colonic myoelectrical activity have shown that spike potentials were the trigger that initiated a contraction and slow waves were the timing mechanism that synchronised the spike potentials and thereby the timing of the contractions, (cf Section 1). Having found a motor abnormality in the Irritable Bowel Syndrome, a corresponding electrical abnormality was sought. However, in vivo studies in the human have had to withstand different and less precise techniques, such as extracellular electrodes rather than intracellular, transmucosal insertion rather than seromuscular and in motor activity, intraluminal pressure measurement rather than implanted strain gauges.

Recently Chambers et al 1981 recorded the myoelectircal activity from human colon in vitro and with the aid of computer analysis, were able to detect a single fundamental frequency of slow wave 2 - 9 cpm and extra components due to harmonies of that frequency. Whether this work can be extrapolated to explain in vivo electrical activity

further studies may show.

In vivo Electrical Activity

In vivo electrical activity recordings have concentrated mainly on the slow wave activity. Whereas in the stomach antrum or small intestine, only a single frequency of the slow wave has been detected (Kwong, 1969) in the human colon two predominant frequencies have been detected (Snape et al, 1976; Taylor et al, 1974; Sarna 1980) The lower frequency 3 cpm has a greater incidence in the IBS rather than the higher frequency 6 - 9 cpm. Unfortunately, recordings of electrical activity in vivo differ from those in vitro in the following ways:

1) The slow wave in vitro has a cleaner, repetitive waveform whereas in vivo the slow wave has a more variable shape and configuration.

2) The frequency of the slow wave is lower in vitro that in vivo.

3) The amplitude of the slow wave varies more in vivo than in vitro.

4) In the colon, two frequencies have been detected in vivo whereas only one frequency has been observed in vitro.

Many reasons have been suggested for these inconsistencies: differences in electrode size and site of insertion, as mentioned above, neuro-humoral influences in vivo, ischaemia at the site of attachment of the mucosal suction cup releasing kinins, prostaglandins, change in pH and metabolite accumulation. A current hypothesis in vogue is the loosely coupled oscillator theory (Sarna et al, 1971) where the smooth muscle fibres or small groups of fibres have their own inherent rhythm of slow wave frequency (oscillator); the highest frequency oscillator would tend to influence its neighbours by driving them at the faster rate. This influence appears to be short lived, possibly due to the oscillators or pacemakers being

loosely coupled, and a second pacemaker at a different frequency would take over. It has been suggested that where the extracellular electrode is placed close to numerous oscillators, more than one rhythm might be detected and this may be the basis for the recording of slow waves in two frequency ranges.

Detecting colon Electrical Activity

Although electrodes have been implanted into the seromuscular layer of the colon in pateints undergoing an unrelated operation, cholecystectomy (Sarna et al, 1980), most studies of human electrical activity have employed electrodes applied to or through the colonic mucosa. Electrode wire wrapped circumferentially around an intraluminal polyethene tube (Bueno, 1980) detected mucosal (and faecal) movement artefacts more than any myogenic electrical activity. Snape et al, 1976 clipped bipolar electrodes to rectal and colonic mucosa and direct contact with the muscle was not achieved. Taylor et al have used a suction cup technique (Waterfall, 1972) where uni- or bipolar electrodes penetrate the mucosa and muscle layer by applying suction to the surrounding cup. It is not possible to determine whether the trans-mucosal electrode has penetrated the circular or taenia layer. There also remains the effect of faeces in the lumen dislodging or jarring the luminal electrode and similarly the effect of local contractions on the electrode, both of which may cause movement artefacts. Although movement artefacts are generally recognisable as such, contractions of the smooth muscle, by their slow and rhythmic nature, may produce movement artefacts which, by their wavelike character, may be interpreted as a true electrical rhythm.

Slow Wave Activity

To date, motility studies have shown that the IBS does not differ from normal controls in the resting state but does show a significantly greater increase than normal when stimulated with Neostigmine, CCK etc. (Harvey and Read, 1973).

Measurements of myoelectrical activity in the IBS have shown an increased incidence of 3 cpm electrical slow wave activity when compared with normals (Snape, 1976; Taylor, 1978 (a)) and this

abnormality persists in relapses and remissions (Taylor, 1978, (b)) which suggests a fixed myoelectrical abnormaltiy as a basis for the motor abnormality.

Motility Studies in the Irritable Bowel Syndrome.

"Motility" of the colon implies the physical activity through which it performs its functions. Early studies of "motility" employed intraluminal pressure studies (Almy, 1949; Chaudhary, 1961) and more recently these have been combined with electrical recordings of the colonic smooth muscle (Taylor, 1974; Snape, 1976). So as to avoid confusion, studies of the colonic contractions or their secondary effects on intraluminal pressure or transit will be termed "motor activity" studies, and those recording electrical potentials and slow waves will be termed "electrical" or "myoelectrical activity" studies.

Almy et al, 1949, studied intraluminal pressure in patients with spastic constipation. Although large balloons were employed they showed a clear relationship of high pressure motor activity in response to discussion of emotional topics. Chaudhary and Truelove, 1961, studied three groups: Irritable Bowel Syndrome, Ulcerative Colitis and normal controls and found that emotional topics increased colonic motor activity in all three groups.

Whorewell et al, 1981, showed that oesophageal motility (pressure studies) was abnormal in the IBS. In addition, Cann et al, 1983, measuring stomach emptying time and small bowel transit time with radioisotopes showed that gastric emptying time was no different in the IBS compared with a control group but small bowel transit time was rapid in the IBS with diarrhoea and slow in the IBS with constipation when compared with the control group. The abnormalities in motor activity of many parts of the the gastrointestinal tract in the IBS have resulted in the concept of an abnormality of the whole intestine from oesophagus to rectum and hence the name "Irritable Bowel Syndrome" rather than Spastic Colon, Mucous Colitis etc.

Effect of Stimulation

Intraluminal pressure studies of the colon (Chaudhary and Truelove, 1961, Misiewicz et al, 1966; Wangel and Deller, 1965) and myoelectrical activity (Snape, 1977; Taylor, 1978; Sullivan, 1978) all show an increased sensitivity to stimulation by Neostigmine. In the basal, resting state, pressure wave activity was diminished in the diarrhoea group who were symptomatic at the time of study (Chaudhary and Truelove, 1961; Wangel and Deller, 1965; Misiewicz et al, 1966) and increased in the symptomatic constipated group. Various other stimuli have shown a significantly increased response when compared with a control group: Cholecystokinin (Harvey and Read, 1973), food (Connell, 1965; Misiewicz, 1966, Sullivan, 1978), emotions (Chaudhary and Truelove, 1961) Pentagastrin (Taylor, 1974) and deoxycholic acid (Taylor, 1980).

Correlation of Abdominal Pain with intraluminal pressure.

Holdstock et al, 1969, showed that the abdominal pain in a group of patients with the IBS correlated with intraluminal pressure waves in the small and large bowel. Ritchie, 1973 inserted a balloon into the sigmoid colon in order to stimulate the bowel by distension. Although his control group were mixed normal/constipated he showed that the IBS group tolerated lower volumes of distension and suffered pain in the abdomen and back. In view of previous motility studies showing the Irritable bowel responding more vigorously than normal to stimuli, he proposed the Hyperalgesia hypothesis. Mitra et al, 1974, showed that there was an increased response in the IBS to rectal distension and suggested that there was a motor disorder in the IBS. Latimer et al, 1979, disagreed with Ritchie suggesting that his control group, by including constipated individuals biased its response to testing and gave a low reading. They repeated this work with poster volunteer normals and a third group of patients, psychologically matched to the IBS group and with no bowel symptioms. No difference was observed between the three groups. However, it is unfortunate that the balloons were placed in the rectum rather than the sigmoid colon so Ritchie's experimental criteria were not satisfied.

Few investigators in the IBS have combined physiological and psychological studes but recently Whitehead et al 1980 compared diarrhoea-predominant and constipation-predominant patients. Rectal balloons were used to stimulate by distension and record intraluminal pressure in the two groups who were subsequently tested psychometrically.

Two, large 5 cm balloons were inserted to the recto-sigmoid and rectum 'without the aid of a proctoscope' which made their postition approximate and unlikely to be in the rectosigmoid. A confused picture of the anal sphincters was offered and it is difficult to see how they differentiate fast contractions, 6 - 9 cpm, from multiple slow contractions 3 cpm along the length of the 5 cm balloon. However they confirm that at rest there was no difference between normals and the IBS but after stimulation by distension of the balloon, there were increased contractions in the IBS group. The diarrhoea-predominant group had significantly more fast contractions than the constipated IBS or normals. Taking the above criticism into account regarding the balloon size, there would still appear to be a significant increase in motor activity in the diarrhoea-predominant IBS group. It must be recognised that both IBS groups in Whitehead's study complained of abdominal pain and do not correspond with Chaudhary and Truelove's classification ref: painless diarrhoea. Diarrhoea, per se, was associated with diminished motor activity and intraluminal pressure waves in the colon (Connell, 1961) and the pain of the IBS can be replicated by distending a balloon within the colonic lumen (Ritchie 1973). The diarrhoea-predominant IBS was associated with increased motor activity which in turn was directly related to the pain. It must be concluded that:

1) The mechanism of diarrhoea production is different in the IBS

2) The contractions are propulsive rather than segmental

3) The small intestine and proximal colon, already known to have increased motor activity in the IBS, may be implicated, for example, by rapidly transporting liquid stood from small intestine to distal

colon, diarrhoea would result. The distal colon might respond by producing vigorous segmenting contractions and pain.

METHODS OF DETECTING MOTOR ACTIVITY OF THE COLON

Introduction

As the colonic smooth muscle contracts in order to perform its function, so a number of parameters alter and may be measured. For example, intraluminal pressure may vary according to the strength of contraction and this has been used extensively as a measure of activity of the muscle contractions.

Criticism of Methods

1 Inspection

The contractions of the intestinal smooth muscle has been studied by direct inspection in humans on war wounded with exposed loops of bowel (Weeks, 1946) and at operation, but these are non-physiological situations making interpretation difficult. In animal studies, Bayliss and Starling, 1899, 1900, found inspections of the intestinal contractions important in interpretative recordings of intraluminal pressure obtained from large balloons.

However, radiological screening has been a more effective method of inspecting the colon and its contractions.

Cannon in 1901 provided an early description of the contractions of the human intestine in vivo. He observed that segmentation (non-propulsive contraction) was the predominant motor component in the small intestine and peristalsis was superimposed on this. He recognised that the usual movement of the proximal colon and caecum was "antiperistalsis" but which we recognise now as being retropulstion rather that true peristalis in the opposite direction. His studies showed that emotion had a profound inhibitory effect on both small and large instestine.

Holznecht, 1909 observed mass movement radiographically with the transfer of a large volume of colonic content from proximal to distal colon. Williams, 1967, described his observations on barium enemas

and his stripping wave is equivalent to mass movement.

As a method for scientific study of motility, inspection of the contractions remains a subjective observation and as such is unavailable to statistical analysis. For this reason and due to the harmful effects of ionising radiation, radiological screening has largely been abandoned as a research tool.

2. INTRALUMINAL PRESSURE

a) Balloons

The early studies of intraluminal pressure employed large water filled balloons (Bayliss and Starling, 1899; Templeton and Lawson, 1931; Posey et al, 1948), a large balloon being one that fills the lumen of the intestine.

Bayliss and Starling, 1899, 1900, recognised that the intestinal wall was the seat of continuous rhythmic contractions and the extent and force of these contractions varied with the tension of the intestinal wall. The two muscle layers always contracted simultaneously and they proposed:

> Starling's Law which described the mechanism of peristaltic contraction as excitation and contraction above a bolus and inhibition and relaxation below.

They claimed that absence of either of these conditions would prevent the onward progression of the bolus.

Using large rubber balloons filling the lumen of the bowel they found that their physical presence stimulated contractions in their own right.

Templeton and Lawson in 1931 studied the intraluminal pressure of the dog colon with large balloons and identified three types of contraction: Types I, II, and III and these have been identified in subsequent human studies (Posey et al, 1948).

b) Open Ended Tube (OET)

Brody et al, 1940, measured intraluminal pressure with an open ended tube which was not perfused and consequently was subject to blockage. Twelve years later Quigley and Brody criticised the balloon technique and suggested the use of a fluid-perfused open ended tube. Lorber and Shay, 1954, also criticised the balloon method listing nine reasons, but the important one being that the balloon responds to changes in volume and pressure whereas the open ended tube responds to pressure alone. Those conclusions have been supported by Connell in 1968.

Following the criticism of large balloons in stimulating the bowel and thereby increasing motor activity, miniature balloons were employed (Parks and Connell, 1969; Misiewicz et al 1966; Harvey and Read, 1973) despite the remaining criticism of this method.

Ritchie et al 1962 compared the two methods on the test bench and described the differential pressure unit. He concluded that the open ended tube registers pressure accurately but could not differentiate between an active contraction of the gut and passive distension. The balloon sensor transmitted not only pressure changes but also tension within the wall of the balloon. The differential unit was composed of a balloon and an open ended tube recording from the same level and connected to either side of the transducer diaphragm. Thus pressure changes would cancel themselves out by their opposing action on the transducer diaphragm. However, when the balloon was compressed by a local contraction the tension within the balloon wall was increased and this was registered by the differential pressure unit. In this way local contractions were detected and differentiated from passive distention. However, to do this the balloon must be compressed. If it were large enough to fill the lumen and record all the local contractions it would act as a bolus and stimulate the smooth muscle. Conversely, if it were very small, the contraction would have to be particularly strong in order to compress the balloon and hence be registered.

c Radiotelemetry "pill"

The "radio pill" is a small pressure-sensitive device that emits a constant frequency radio wave. Changes in pressure, while in the lumen of the bowel, alter the frequency of the wave which is detected by loop aerials outside the subjects's body. It is necessary to have three loops in three different planes so as to detect the radio frequency as the emitter changes position.

While this enables recordings of intraluminal pressure from usually inaccessible regions eg small bowel and proximal colon (Holdstock et al, 1970; Bloom A. A. et al, 1968) it acts as a bolus and is moved on

down the bowel. Hence the recordings from one postion are quite short and no differentiation between segmenting or propulsive contractions is possible.

Pressure measurements are an imprecise measure of the intestinal contractions because they measure the effect of contractions on the intraluminal pressure rather than the contraction itself. When continuity exists between segments, then a contraction in one segment will increase pressure over many segments.

3 TRANSIT TIMES

The time taken for all or part of an ingested marker to pass through the gastrointestinal tract has been described as the transit time.

Swallowing a number of markers in a single dose and examining the stool to determine the time for 80% to be passed (Hinton J M et al, 1969) or swallowing markers over successive days and recording the progress through the alimentary canal (Cummings et al, 1976) or examining a single stool (Cummings et al, 1976) have been used as an indication of overall motor activity, mainly in studying the effects of different diets (Cummings 1976).

There are three basic criticisms of whole gut transit times:
1 Wyman et al, (1978), showed how variable transit times and size of individual stools were in 12 healthy subjects studied over 4 - 6 weeks. This makes results from Transit Times difficult to interpret.

2 In following radiopaque markers through the intestine, the markers, swallowed first precede those taken second until the caecum is reached. The transit time through the small bowel is relatively uniform eg 8 - 12 hrs but while in the caecum the markers may remain for 2 - 3 days and when eventually passed per rectum, the markers swallowed last may precede those swallowed first.

3 While increased motor activity in the small bowel may result in rapid transit through the small bowel, increased motor activity of the colonic smooth muscle delays transit because segmentation is the main

motor activity of the colon - especially the distal colon.

Hence transit times involving the colon are poor indications of motor activity of the GI tract as a whole. However transit times of the small bowel or emptying times of the stomach are good indicators of motor activity of that area. Gastric emptying time and small bowel transit time may be estimated by recording the progress of radioactive markers with a gamma camera.

Transit studies are most useful in the investigation of constipation where serial abdominal radiographs indicate where the delay in transit exists.

STRAIN GAUGES

a strain gauge is composed of a metal grid whose electrical resistance changes when subjected to alteration in length of the gauge. This characteristic has been employed to measure change in length of smooth muscle and hence record contractions in the laboratory animal (Bass, 1965). These strain gauges require operative implantation on to the seromuscular layer of the bowel wall and are usually not retrieved unless the animal is sacrificed. This method of insertion is not applicable to humans but the properties of the strain gauge have distinct advantages over intraluminal pressure recordings in that they detect changes in length of the bowel wall (and therefore the smooth muscle) and are not affected by muscular activity of adjacent segments as are pressure sensitive devices.

For this reason, strain gauges were used in the construction of the Strain Gauge Probe which has been used in humans to detect contractions of the smooth muscle directly.

AIM

2 Develop a method for detecting contractions in human bowel directly.

3 Detect changes in tone and differentiate this from passive

distension or deflation.

4 Differentiate segmenting contractions from propagated contractions and detect their direction and rate of spread.

5 Study the above parameters in the Irritable Bowel Syndrome and compare them with normals.

THE STRAIN GAUGE PROBE

The Strain Gauge Probe was designed to detect contractions at three sites 50 millimetres apart together with intraluminal pressure at the level of the strain gauge pair at the tip. Construction details are given in the General Methods Section.

With the present arrangement of strain gauges and open ended pressure tube it was possible to detect and differentiate the following:

1 Character or type of the colonic contractions

2 Change in smooth muscle tone

3 Distension

4 Deflation

5 Segmenting contractions

6 Propulsive contractions

7 Retropulsive contractions

METHODS

Subjects

Informed consent was obtained from eight normal volunteers and 23 patients suffering from the IBS. The normal control subjects were patients from a general surgical ward who had not undergone a recent operation and who had no symptoms of abdominal pain or alteration in bowel habit.

The IBS was diagnosed in 23 patients by two consultant gastroenterologists in whom the following criteria were satisfied:

Compatible history
All had abdominal pain
Most suffered from distension, borborygmi, passage of mucus per rectum
Constipation, (more than 3 days per stool) or,
Diarrhoea, (more than 3 stools per day)

Normal general and rectal examination
Normal sigmoidoscopy
Normal haemoglobin and Erythrocyte Sedimentation Rate
Normal Stool Culture and Microscopy
Normal Barium Enema
Normal Barium Meal/gastroduodenoscopy (where indicated by site of the pain or other symptoms).

The recording equipment has been described in the General Methods Section.

Each subject had a light breakfast (cup of tea, two slices of toast, butter and marmalade) three hours prior to study.

The strain gauge probe was inserted through a sigmoidoscope so that the strain gauges at the tip were at the rectosigmoid junction, 15 - 17 centimetres from the anal verge. The sigmoidoscope was withdrawn and the external portion of the probe attached to the right upper thigh with adhesive tape.

Two hours recording of strain gauge contraction recordings at three levels and pressure recording at the rectosigmoid junction was made on heat sensitive paper (Devices pen recorder) and magnetic tape (Racal Store 4 FM recorder).

A subcutaneous injection of 0.6 milligrammes of Neostigmine was given after one hour basal recording and followed by a further sixty minutes recording.

Analysis

Each patient's recording was analysed visually and the following parameters determined:

1 The Types of Contraction were identified by inspecting the traces.

2 The Correlation Coefficient, r, was calculated from the comparison of the Contraction and Pressure recordings at the rectosigmoid junction.

3 The Motility Index of contraction and pressure waves was determined from the following

Amplitude (mm) x Duration (mm) ÷
Total Duration of Recording Period (minutes)
Motility Index (MI) was calculated before and after stimulation and the paired 't' Test applied.

4 Detection of Tone changes and differentiation from passive distension or deflation.

5 Propagation of the contractions
Rate of spread
Direction of spread

RESULTS

1 TYPES OF CONTRACTION

Three types of contraction were identified according to their rate per minute (frequency) and their graphic configuration:

Type A contractions were low amplitude contractions with a frequency of 6 - 10 per minute, (Figure 37).

Type B Contraction was a complex contraction composed of a series of Type A contractions superimposed on a raised baseline, (Figure 37).

Type C Contractions were contractions with a simple waveform, variable amplitude but at a rate of 2.5 - 3.5 contractions per minute (Figure 38).

Association with changes in intraluminal pressure

Type A Contractions were detected by the strain gauges where no change in intraluminal pressure was detected at that level.

Type B Contractions were associated with Type III pressure waves (Templeton and Lawson, 1931) which closely resembled the B contractions in shape and configuration.

Type C Contractions were associated with intraluminal pressure waves of a similar shape and identical rate, 2.5 - 3.5 per minute.

IBS v Control

The presence of B and C contractions in the two groups was analysed in Table 12. Although more C contractions were detected in the IBS group the difference was not statistically significant.

IBS - Type of contraction v abdominal pain

Six of the IBS patients were symptomatic at the time of recording. The

abdominal pain was related to C contractions with high amplitude and was not related to B contractions. However, within the IBS group where C contractions were more commonly detected, no stastistical difference in the incidence of C contractions could be demonstrated when the patients were symptomatic, (Table 13).

Discussion

B and C contractions were associated with intraluminal pressure waves whose configuration and frequency were the same. Since the strain gauges detected local contraction events it would appear that the most pressure waves were due to local contraction activity rather than the summation of activity over many segments. However not all contractions were associated with pressure changes (although most were) and not all pressure waves were associated with local contractions.

The 3 cpm electrical slow wave activity was more common in the IBS and this was related to pressure changes at the same frequency. The studies with the strain gauge probe would suggest that this was related to the C contractions, which were more common in the IBS group. The contractions had the same frequency range (2.5 - 3.5 cpm) as the 3 cpm electrical slow wave. Although classical interpretation of this suggests that the electrical rhythm produces the motor rhythm, in view of the doubt cast upon the intraluminal and transmucosal recording methods of myoelectrical activity, this does not diminish the thesis that the in vivo recorded electrical activity is in whole or in part, a contraction movement artefact.

Figure 37

Recording in humans with the Strain Gauge Probe showing A and B contractions with Type III pressure waves correlating with the B contractions.

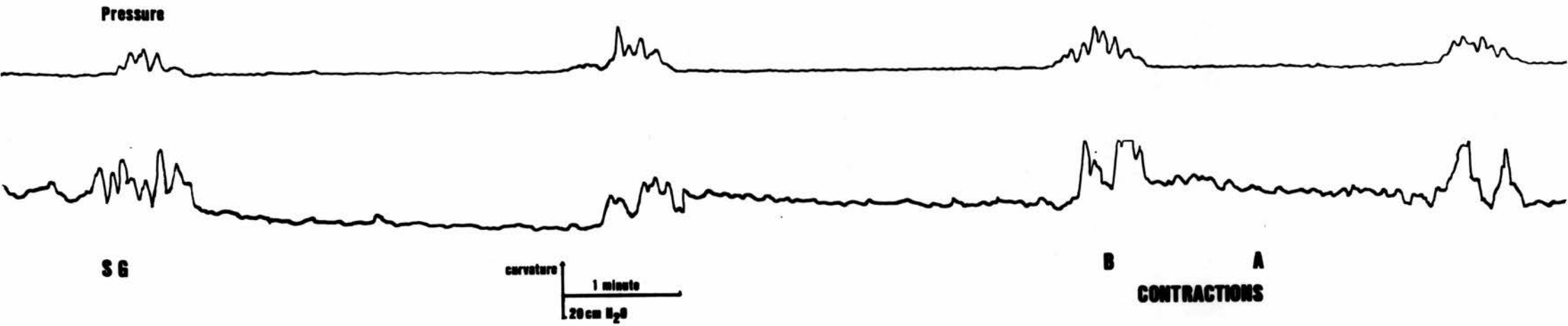
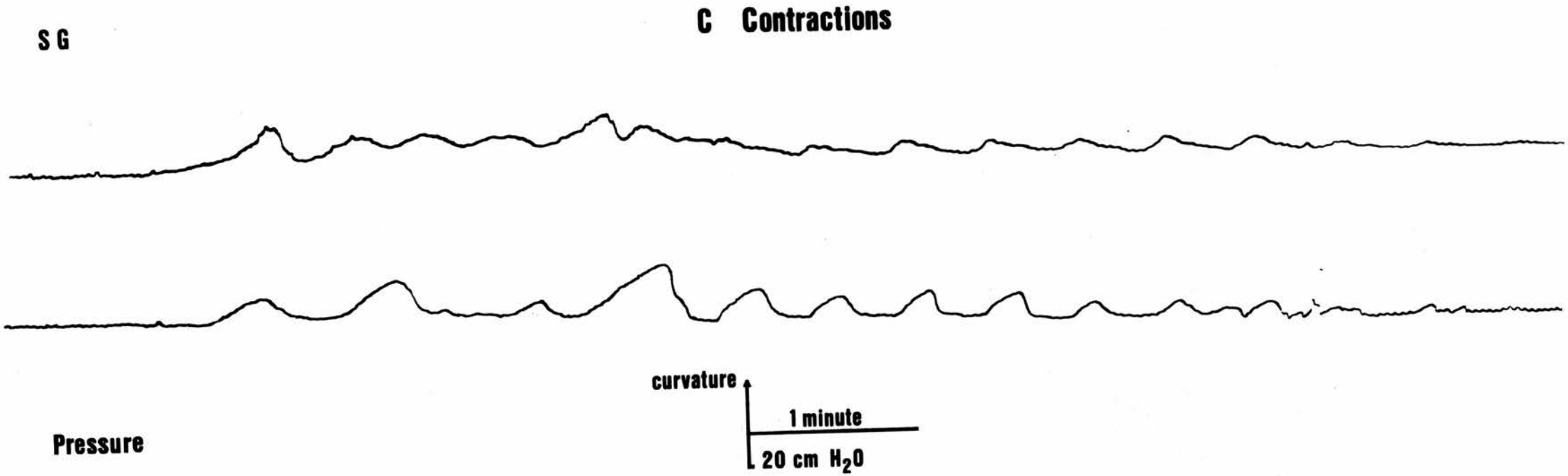

Pressure
S G
curvature
1 minute
20 cm H_2O
B
A
CONTRACTIONS

Figure 38

Recording with the Strain Gauge Probe showing the C contractions with their association with the pressure waves.

Note the rise in baseline of both the strain gauge and pressure traces.


S G
C Contractions
curvature
1 minute
20 cm H_2O
Pressure

2 COMPARISON OF CONTRACTION AND PRESSURE RECORDINGS.

Method

Local contractions and intraluminal pressure were recorded from the tip of the probe, situated at the rectosigmoid junction. The Motility Index (MI) was calculated before and after stimulation with Neostigmine and the ratio of basal MI/stimulated MI was determined for both the strain gauge and pressure recordings. Eleven subjects from a mixed group of patients were studied. These subjects had no gastrointestinal symptoms or pathology.

The ratio of basal MI/stimulated MI from each recording method was compared and a correlation coefficient was calculated.

Results

Table 14 reveals that no correlation exists between the two methods on the basis of the motility indices.

Discussion

Visual inspection of the recordings showed that close correlation exists between the strain gauge contraction and the pressure recordings where there was specific contraction activity. Hence, Type B and C contractions were associated with pressure wave activity whose graphic configuration bore a close resemblance to the strain gauge traces. Type A contractions were not associated with changes in intraluminal pressure and this may have contributed to the poor correlation.

The comparison of Motility Indices may be an inefficient method of correlating these two methods, considering a visual correlation existed in part of most traces. However, more activity was detected by the strain gauges than appeared in the pressure recording, and a greater increase, following Neostigmine, was revealed by the strain gauges. Both of these factors would influence the correlation in Motility Indices.

The poor correlation also serves to show that the two methods were either not recording the same event or that one method was influenced by extraneous activity in addition to recording the local motor activity. The strain gauge pair at one point in the lumen of the colon was affected by the motor activity of the segment in which it is situated. In contrast, the pressure at the same point in the lumen was affected by local motor activity and in addition, by motor activity in adjacent segments where the lumen was patent between the segments.

3 MOTILITY INDEX (MI)

Calculation of Motility Index

Method

The MI was calculated from the paper recordings with the formula

$$\text{Motility Index} = \frac{\text{(Amplitude X Duration) Millimetres}}{\text{Total Duration Recording Period (minutes)}}$$

The MI was determined for the strain gauges at 10 and 15 centimetres from the anal verge in both control and IBS group. The MI was calculated before and after stimulation with Neostigmine and the Paired Students 't' Test applied.

Results

Patients with the IBS showed a significant increase in their colonic and rectal motility as shown by the motility indices, (Table 15) $p < 0.01$.

The control group also showed a significant increase in the colonic motility indices at the rectosigmoid junction, $p < 0.02$, (Table 16) but not in rectal motility at 10 centimetres from the anal verge, $p < 0.5$.

The ratio of basal MI to stimulated MI recorded at 15 cm was calculated and a comparison between the control and IBS group showed no significant difference, $p < 0.5$, (Table 17).

Discussion

It was not unexpected that the motility indices showed a significant increase in motility in response to Neostigmine. The exception was the strain gauge pair at 10 centimetres in the control group. Only three recordings contained data capable of analysis and this small

number may have contributed to the result.

Particular interest is aimed at the comparison of the Control and IBS groups showing no significant difference between the two. This contrasts with other published reports of motility studies in the IBS where stimulation produces a significantly greater response in the IBS group.

4. CHANGE IN SMOOTH MUSCLE TONE

Definition

Change in tone was defined as a change in the active length of the smooth muscle.

With the Strain Gauge Probe it was possible to detect active changes in smooth muscle tone, and differentiate this from passive events such as distension and deflation.

Change in tone was recognised by an alteration in the baseline of both the strain gauge and the pressure recordings. Hence a rise in tone was detected by a rise in the baseline of both the strain gauge and the pressure trace (Figure 39). In contrast, a drop in tone was detected by a lowering of the baseline of both the strain gauge and the pressure recording.

Passive events, such as distension (Figure 40) or deflation (Figure 41) were detected by a corresponding decrease or increase in baseline of the strain gauge with either no change or an inverse response in the pressure baseline.

Table 18 illustrates this.

The strain gauge probe measured change in tone at one point, that is at the rectosigmoid junction in this study. More points could be studied with the incorporation of more pressure lines.

Method

Ten patients with the IBS and eight control patients were studied. Recordings were taken for 60 minutes in the resting state followed by 60 minutes after a subcutaneous injection of 0·6 milligrammes of Neostigmine.

All records were analysed for changes in baseline >10 small squares (= 10 centimetres of water in Pressure) and lasting >1 minute.

Figure 39

Recording with the Strain Gauge Probe showing an increase in smooth muscle tone marked by the broken line.

Note the drop in baseline of the strain gauge recording only.

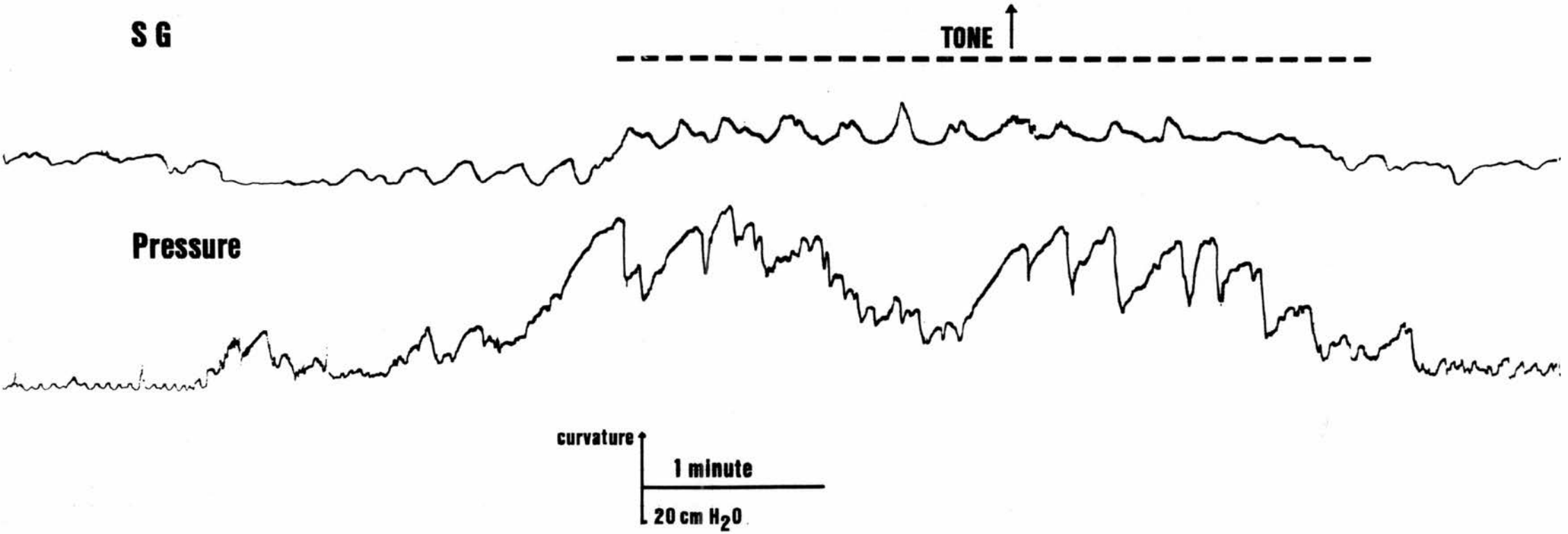

S G
TONE
Pressure
curvature
1 minute
20 cm H_2O

Figure 40

Recording with the Strain Gauge Probe showing Distension at the rectosigmoid junction.

Note the drop in baseline of the strain gauge recording only.

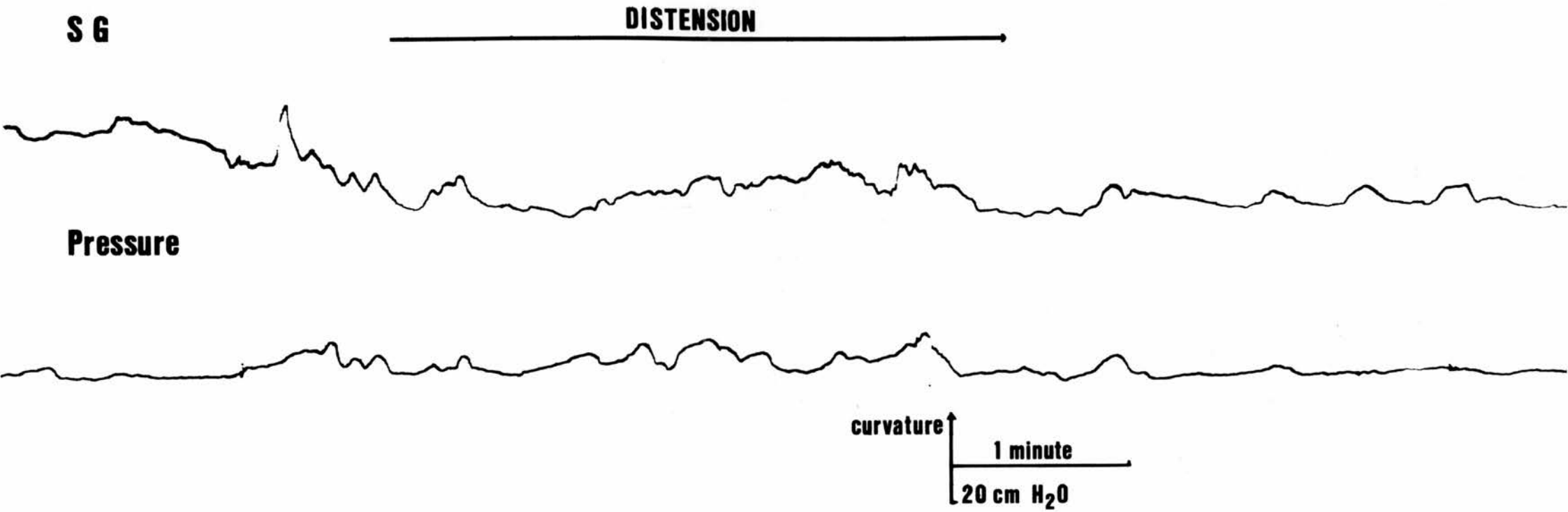
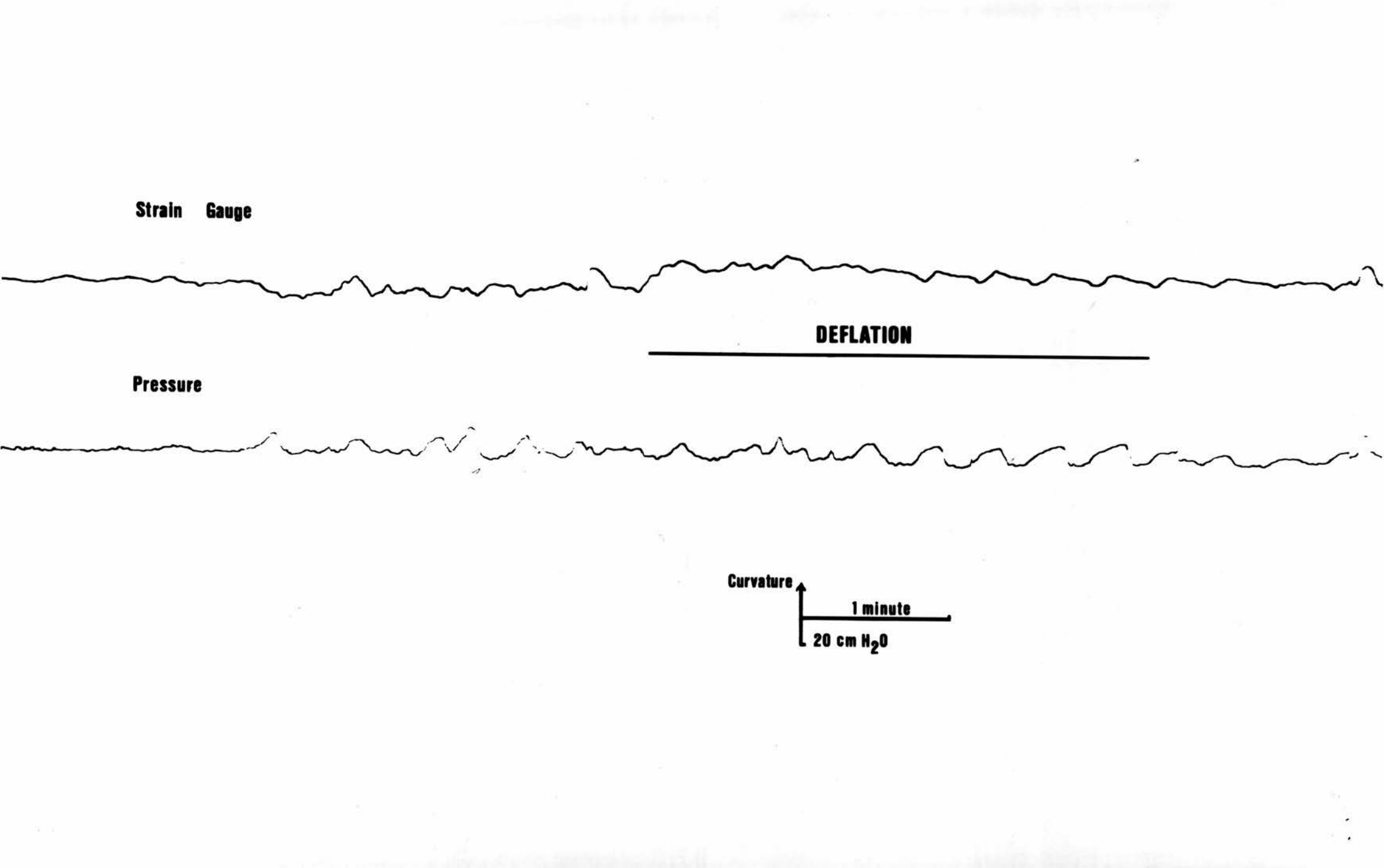

S G
DISTENSION
Pressure
curvature
1 minute
20 cm H_2O

Figure 41

Recording with the Strain Gauge Probe showing Deflation at the rectosigmoid junction.

Note the rise in baseline of the strain gauge recording only.


Strain Gauge
DEFLATION
Pressure
Curvature
1 minute
20 cm H_2O

Type III pressure waves have been considered to represent an increase in Tone (Templeton and Lawson 1931). B contractions were closely associated to Type III pressure waves and the number of B contractions and Type III pressure waves, together with their simultaneous presence, were recorded.

Results

Changes in Tone of the smooth muscle was an uncommon event. An increase in Tone at the rectosigmoid junction was detected in one patient and in 2 control patients and all after stimulation with Neostigmine, (Table 19).

Distension and Deflation were equally uncommon. In one IBS patient, after stimulation with Neostigmine, abdominal distension was experienced at the same time as distension of the rectosigmoid colon was recorded.

Type III pressure waves were very uncommon without the corresponding presence of B contractions, (Table 20).

In contrast, B contractions were recorded in isolation in three patients. However, B contractions were detected in seven patients and associated with Type III pressure waves in six.

Discussion

Changes in smooth muscle tone were clearly detected and differentiated from passive events: distension and deflation.

As prolonged events ($>$ 1 minute), changes in tone were uncommon. In contrast, increase in tone was quite frequently demonstrated by the B Contraction/Type III pressure correlation, which tended to be of shorter duration.

The significance of changes in tone at the rectosigmoid junction in the Irritable Bowel Syndrome has yet to be determined.

5 PROPAGATION OF CONTRACTIONS

Method

Identification

Propagated contractions were identified by the time delay between similar contractions recorded by the strain gauges spaced 50 millimetres apart. B or C contractions were identified in each of the strain gauge recordings and, propagation was demonstrated where a time delay existed between the strain gauges at 15 and 10 centimetres and 10 and 5 centimetres from the anal verge. Some propagated contractions, B or C occurred individually preceded by an inactive period whereas other contractions occurred in 'runs' or complexes. The initiation of the contraction complex in the strain gauge recordings was used to identify propagation and where present, it was counted as 'one' propagated contraction (or complex).

Three parameters were identified from the strain gauge contraction recordings:

a) Propagated or Segmenting contractions

b) Direction of Propagation

c) Rate of Spread

a) PROPAGATED CONTRACTIONS

Results

Controls v IBS

There was no significant difference between the control and IBS groups in the incidence of propagated contractions as a whole, (Table 21).

Type of Contraction

There were significantly more B contractions propagated than C Contractions which tended to be segmenting contractions (Table 22).

$p = 0.019$.

Symptomatic V Asymptomatic

In the IBS group, eight patients were symptomatic, that is they experienced abdominal pain during the recording period and this was the same pain of which they usually complained.

No propagated contractions were detected during a symptomatic period in which the patient experienced abdominal pain. By contrast, there were more propagated contractions during pain-free periods than segmenting contractions. This difference was statistically significant ($p = 0.004$ - Table 23).

Effect of Stimulation on Propagated Contractions (propulsive and retropulsive)

There appeared to be little predictable effect on propulsive or retropulsive contractions by stimulation with Neostigmine. Rarely did the incidence of propagation remain unchanged by stimulation but the change might be an increase or a decrease in the number of propagated contractions, (Figure 42).

b) DIRECTION OF PROPAGATION

Propagated contractions were identified as propulsive or retropulsive according to their direction of spread: propulsive contractions were propagated towards the anus and retropulsive contractions were propagated orally.

The IBS group were subdivided into two groups: the diarrhoea predominant group were composed of patients in whom abdominal pain and frequent bowel motions were a dominant feature (greater than 3 per

day). The constipation predominant group had abdominal pain and the absence of bowel motions for a period greater than three days as a major complaint.

The recordings from the controls and both IBS groups were analysed for the presence of propulsive, retropusive and segmenting contractions in the resting, basal state and after stimulation with Neostigmine, 0·6 milligrammes subcutaneously.

Basal Recordings

In relation to the total number of subjects in each group, there was no significant difference between the control and the constipation predominant IBS group. In contrast, there was significantly more propagated contractions, both propulsive and retropulsive, in the diarrhoea predominant IBS group, (Table 24).

Effect of Stimulation

Stimulation with Neostigmine had little overall effect on the incidence of propulsive, retropulsive or segmenting contractions in the control and IBS groups, (Table 25). However, there remained the same increased incidence of propagated contractions in the diarrhoea predominant IBS group in comparison with the constipation predominant IBS and controls.

c) RATE OF SPREAD

Method

The rate of spread was calculated from the distance between the strain gauges (5 centimetres) divided by the time difference between the recorded propagated contractions

$$\text{Rate of spread} = \frac{5}{n} \times \frac{52}{60} \text{ centimetres per second}$$

where n = number of small squares
52 small squares = 60 seconds.

The IBS group were subdivided into two groups: the diarrhoea predominant group were composed of patients in whom abdominal pain and frequent bowel motions were a dominant feature (greater than 3 per day). The constipation predominant group had abdominal pain and the absence of bowel motions for a period greater than three days as a major complaint.

The recordings from the controls and both IBS groups were analysed for the rate of spread of propulsive and retropusive contractions in the resting, basal state and after stimulation with Neostigmine, 0·6 milligrammes subcutaneously.

Results

Effect of Stimulation with Neostigmine

The effect of stimulation on the rate of spread of propulsive and retropulsive contractions in the IBS groups and the control group is illustrated in Table 26. The variation in each group is quite large and statistical significance was reached in only the control group (propulsive- $0{\cdot}02 > p > 0{\cdot}01$; retropulsive- $0{\cdot}01 > p > 0{\cdot}001$). These results are detailed in Table 27.

Differences between the IBS groups and Control.

Diarrhoea Predominant IBS v Controls

Basal Recordings

In both the propulsive and retropulsive contractions there was a significant difference in the rate of spread between the two groups

(Table 28).

Stimulated Recordings

In both the propulsive and retropulsive contractions there was no significant difference in the rate of spread between the two groups (Table 28).

Constipation Predominant IBS v Controls

Basal Recordings

In the propulsive contractions there was no significant difference in the rate of spread between the two groups, $0{\cdot}1 > p > 0{\cdot}05$, (Table 29).

In the retropulsive contractions there was a highly significant difference in the rate of spread between the two groups, $p < 0{\cdot}001$ (Table 29).

Stimulated recordings

In both the propulsive and retropulsive contractions there was no significant difference in the rate of spread between the two groups, $p < 0{\cdot}5$, (Table 29).

Discussion

Propagated contractions in the rectosigmoid colon and rectum were a relatively common event (12/23 IBS group; 3/8 control group). Propulsive contractions serve to propel the luminal contents along the bowel in its normal progression towards the anus. In contrast, retropulsive contractions act in the reverse manner. The strain gauge probe was positioned at the rectosigmoid junction and the rectum and the physiological significance of this may lie in the function of the rectum rather than that of the colon: the colon serves as an organ of storage and absorption and is usually full of faeces, whereas the rectum serves as an organ of evacuation and is normally empty. When

stool is propelled into the rectum, a sensation of rectal fullness and discomfort is appreciated and with it, a desire to defaecate. If this desire is not satisfied the sensation gradually disappears. The detection of retropulsive contractions in the rectum and sigmoid colon suggest that the rectum may be emptied back into the colonic reservoir, relieving the distension in the rectum and with it, the desire to defaecate.

The direction and rate of spread of propagated contractions was increased by stimulation with Neostigmine in the normal control group. The mechanism of propagation appears to rely on the integrity of the muscularis propria together with the myenteric plexus and this study indicates that cholinergic nerves were involved in the initiation or control of propagated contractions.

The strain gauge recordings clearly show that in the two main types of contraction, B contractions were propagated and C contractions tended to be segmenting. There was a highly significant correlation between abdominal pain at the time of the recording and segmenting C contractions in the IBS group. No propagated contractions were detected when the IBS patients suffered abdominal pain during the recording period. This suggests that segmenting contractions in these patients were intimately involved in the pathogenesis of the abdominal pain in the Irritable Bowel Syndrome.

With regard to propagated contractions, the diarrhoea-predominant IBS group had a significantly greater incidence of propulsive and retropulsive contractions than the constipation-predominant IBS and control groups, which suggests that there may be an inherent abnormality in the diarrhoea-predominant IBS group as this difference exists in the basal state but not when the bowel was stimulated with Neostigmine.

The incidence of retropulsive contractions in the constipation predominant IBS was significantly greater than the control group in the basal state but this difference did not extend to propulsive contractions. The significance of this anomaly in the propagated contractions in this IBS group is not clear. Incomplete evacuation of

the rectum is a well recognised symptom in the IBS (Manning, 1978). Retropulsive contractions may act by emptying the contents of the rectum into the sigmoid colon during the act of defaecation in this group or inhibit the expulsion of faeces out of the anus and thereby producing the sensation of incomplete evacuation.

This study has shown that strong, segmenting contractions were intimately involved in the pain experienced by the patients with the constipation predominant IBS and the diarrhoea predominant IBS was associated with a significantly greater amount of propagated contractions. Both groups experienced abdominal pain but it may be that a different motor abnormality exists between the two IBS groups as a basis of the pain.

CONCLUSION

Myoelectrical recordings in the Rabbit

1 Smooth muscle contraction of the colon was closely associated with amplitude changes in the skin electrical recordings. Skin electrodes on the abdomen detected movement of the bowel within the peritoneal cavity.

2 Electrical recordings from electrodes implanted into the smooth muscle of the colon was also susceptible to contraction movement artefact. Colonic electrical activity in the rabbit was composed of relatively quiescent periods with low amplitude slow waves and the absence of spike potentials. Interspersed with these were the High Amplitude Periods characterised by an increase in amplitude and the presence of spike potentials. The frequency of the colonic slow wave varied from wave to wave but by eliminating the gross movement a continuous simple slow wave rhythm was revealed.

Contraction Recordings in the Human Colon and Rectum

3 Circular muscle contractions were measured directly and three types identified.

Type A contractions were not associated with changes in intraluminal pressure. In contrast, B and C contractions were associated with pressure waves whose configuration and timing were the same.

4 B contractions were propagated in both directions whereas C contractions were mostly segmenting though some were propagated.

5 Change in smooth muscle tone was identified and differentiated from passive events such as distension and deflation. These events were uncommon in both the control and IBS groups although the B contraction/Type III pressure wave were more common and represented increase in tone albeit of shorter duration.

6 Stimulation by Neostigmine increased the Motility Index of the strain gauge recordings in the IBS and control groups but there was no difference between the groups.

7 Contraction recordings in the IBS group, who complained of pain at the time of the recording, revealed a highly significant association of high amplitude, segmenting C contractions with the pain. The pain experienced by these patients originated in the colon during episodes of stronger than normal, segmenting contractions.

8 Two sub-groups within the IBS group were identified: the constipation predominant and the diarrhoea predominant. Segmenting contractions were no more common in the constipation predominant group than in the diarrhoea predominant IBS or control group. In contrast, Propagated contractions were more common in the basal state in the diarrhoea predominant IBS than controls and the constipation predominant IBS.

9 This study suggests that the pathogenesis of the symptoms in the IBS is different between the two IBS subgroups. No intrinsic abnormality persists in the asymptomatic phase of the constipation predominant IBS but recordings taken when the patients were suffering from their abdominal pain show that high amplitude segmenting contractions were present. In contrast, an intrinsic abnormality in the diarrhoea predominant IBS was detected by the increased incidence of propulsive and retropulsive contractions in the basal unstimulated state. The combination of these two subgroups in studies undertaken into the Irritable Bowel Syndrome may mask abnormalities unless these groups are separated.

TABLE 12

	IBS (n=23)	Control (n=8)
B Contraction	8	6
C Contraction	20	5

chi squared = 1·32 (Yates Correction)

0·5 > p > 0·1

The incidence of Types B and C contractions in the two groups is illustrated above. Both types of contraction were detected in some subjects.

TABLE 13 The Irritable Bowel Syndrome

	Pain	No Pain
B Contraction	2	6
C Contraction	7	13

$p = 0{\cdot}485$ (Exact Probability Test)

Eight of the IBS subjects were symptomatic at the time of the recording. The abdomional pain was related to C contractions and not to B contractions although no statistical difference could be demonstrated.

TABLE 14 A comparison of strain gauge and pressure recordings of motor activity at the recto-sigmoid junction.

Strain Gauge			Pressure		
Basal MI (B)	Stimulated MI (S)	Ratio B/S MI	Basal MI (B)	Stimulated MI (S)	Ratio B/S MI
116·7	161·5	1·38	323	274	0·85
293·2	445·3	1·52	96·	136	1·42
97·8	58·3	0·60	19	3	0·16
97·1	332	3·42	294	397	1·35
220	274	1·25	204	145	0·71
151	284	1·88	111	228	2·05
291	300	1·03	240	382	1·59
474	647	1·36	95	136	1·43
5·45	505	92·8	243	219	0·90
102	310·8	3·05	75	383	5·11
42·8	370	8·64	5	133	27

Correlation Coefficient, r = -0·048

The ratio of basal MI/stimulated MI for the strain gauge was compared with the ratio obtained from the pressure recording.

No correlation between the two recording methods could be demonstrated from the comparison of the Motility Indices, (MI).

TABLE 15 Recordings from the IBS group with the strain gauges located at two levels, 10cm and 15cm from the anal verge.

IBS Group

Strain Gauge 10 cm		Strain Gauge 15 cm	
Basal MI	Stimulated MI	Basal MI	Stimulated MI
19·2	192	7·2	72·4
22·5	389	60·5	461·5
57	156·7	298·5	596·5
98	143	293·2	445·3
130	389·7	97·8	58·3
285	263·9	97·1	332
172	225·5	192·6	143·7
		220	274
85	421·7	151	284
70	227	291	300
$t = 3·786$		$t = 3·104$	
$0·01 > p > 0·001$		$0·02 > p > 0·01$	

Motility Indices (MI) were calculated before and after stimulation with Neostigmine.
A significant increase in stimulation was demonstrated at both 10 and 15 centimetres from the anal verge.

TABLE 16

Control Group

Strain Gauge 10 cm		Strain Gauge 15 cm	
Basal	Stimulated	Basal	Stimulated
		474	647
		5·5	505·8
		102	310·8
330	238·5	134·7	456·9
271	349·4	107	213
8	164·6	42·8	370
41	30·6	116·7	161·5
$t = 0{\cdot}618$		$t = 4{\cdot}109$	
$p < 0{\cdot}5$		$0{\cdot}02 > p > 0{\cdot}01$	

Motility Indices were calculated from the strain gauge recordings before and after stimulation with neostigmine.

A significant increase in the motility index after stimulation was seen at 15 cm.

TABLE 17

A comparison of Motility Index Ratios in the Control and IBS groups.

The ratio of basal motility index to stimulated motility index obtained from the strain gauge recordings at 15 cm from the anal verge was compared in the control and IBS groups.

Control	IBS
Basal/Stimulated MI	Basal/Stimulated MI
474/647	7·2/72·4
5·45/505·8	60·5/461·5
102/310·8	206·8/428
134·7/456·9	298·5/596·5
107/213	293·2/445·3
42·8/370	97·8/58·3
116·7/161·5	97·1/332
	192·6/143·7
	220/274
	151/284
	291/300

Student's $t = 1{\cdot}177$

$p < 0{\cdot}5$

There was no significant difference in the motility index ratios between the control and IBS groups.

TABLE 18

The Strain Gauge Probe was able to detect changes in Tone, an active event, and to differentiate this from passive events such as Distension and Deflation.

	Strain Gauge Baseline	Pressure Baseline
Increase in tone	↑	↑
Decrease in tone	↓	↓
Distension	↓	↑ or no change
Deflation	↑	↓ or no change

Where both strain gauge and pressure baselines were deflected in the same direction then an active change in Tone was assumed to have taken place.

Where the baselines were altered in opposing directions or where there was a change in the pressure baseline then a passive event was assumed to have taken place.

Table 19

This shows the number of patients in whom a change in tone, distension or deflation were detected at the rectosigmoid junction.

	IBS n = 10		Control n = 8	
	Basal	Stimulated	Basal	Stimulated
Tone increase	0	1	0	2
Tone decrease	0	0	0	0
Distension	1	1	0	1
Deflation	0	1	0	0

TABLE 20

The number of Type B contractions and Type III pressure waves detected in the IBS and Control groups with the correlation between the two.

	B Contractions	Type III Pressure Waves	B/III Correlation
IBS Patients			
1	-	-	-
2	5	-	-
3	-	-	-
3	-	-	-
4	-	-	-
5	4	-	9
6	-	1	9
Control Patients			
1	5	-	17
2	-	-	-
3	-	-	2
4	-	-	7
5	-	-	6

TABLE 21

The incidence of propagated contractions in the Control and IBS groups.

	Control (n = 8)		IBS (n = 23)	
	Basal	Stimulated	Basal	Stimulated
Propagation	2	3	9	10
No Propagation	6	5	14	13

chi squared = 0·505

$0{\cdot}5 > p > 0{\cdot}1$

There was no statistical difference in the incidence of propagated contractions between the Control and IBS groups.

TABLE 22

The incidence of propagated contractions related to the types of contractions.

	B Contractions	C Contractions
Propagation	8	7
No Propagation	4	14

$p = 0{\cdot}019$ (Exact Probability Test)

More B Contractions were propagated than C Contractions which tended to be segmenting.

TABLE 23

The association between Segmenting Contractions and the IBS patients suffering from abdominal pain.

Contractions	Symptomatic	Asymptomatic
Propagated	0	11
Segmenting	8	7

$p = 0{\cdot}004$ (Exact Probability Test)

In the IBS group, 8 patients were symptomatic during the recording period, i.e., they complained of abdominal pain. Segmenting contractions of high amplitude were detected in all 8 and no propagated contractions were seen.
Propagated contractions were more common in the asymptomatic group.

Table 24

The effect of Neostigmine on propulsive, retropulsive and segmenting contractions in the IBS group.

Contractions	Basal	Stimulated
Propulsive	12	10
Retropulsive	10	9
Segmenting	11	10

chi squared = 5·91

$0{\cdot}1 > p > 0{\cdot}05$

There was not a statistically significant difference in the number patients with propulsive, retropulsive or segmenting contractions before and after stimulation with Neostigmine.

Table 25

The Irritable Bowel Syndrome.

This shows the number of patients in each IBS group in whom propagated or segmenting contractions were detected.

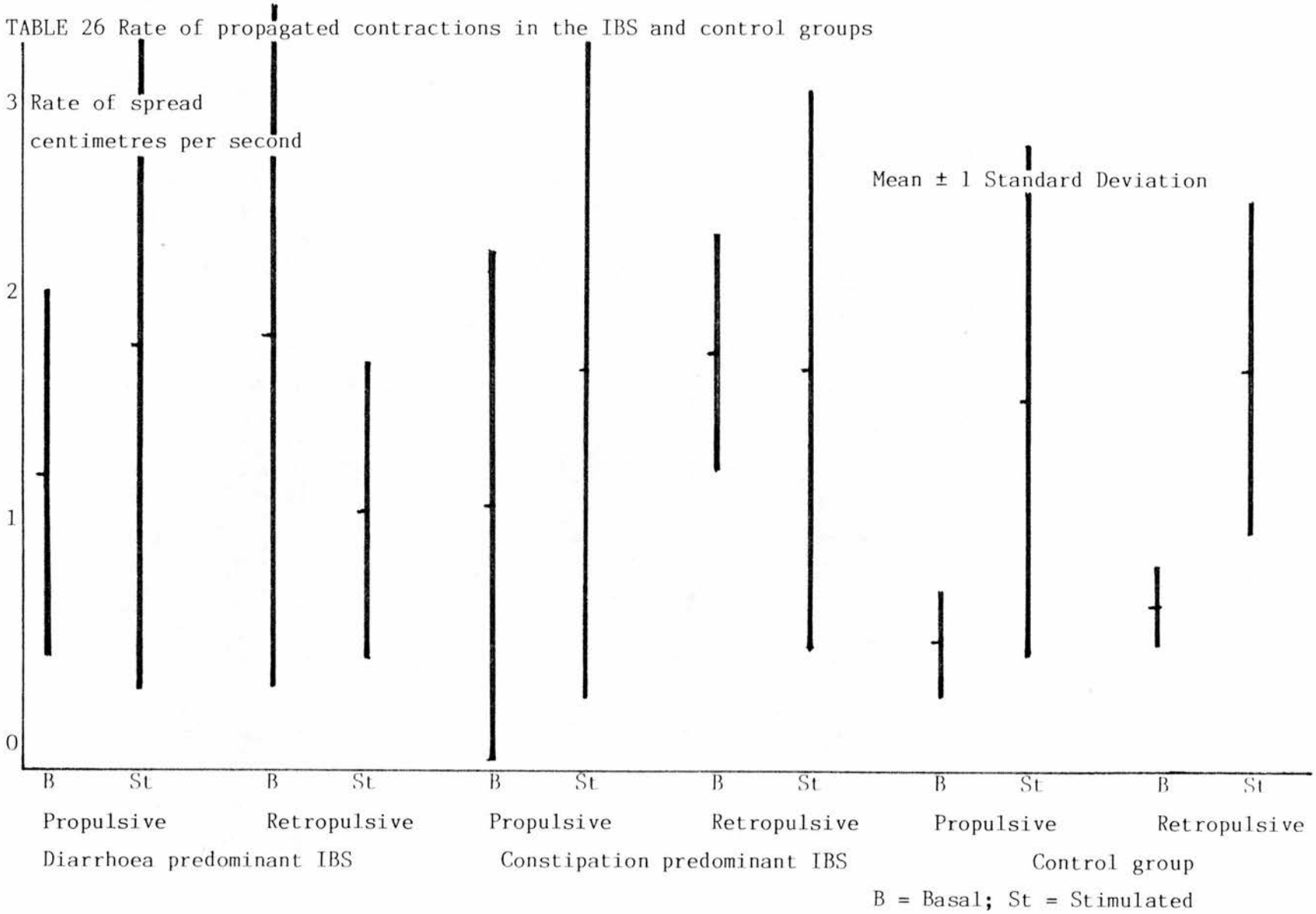
Contractions	Diarrhoea Predominant Patients n = 7	Constipation Predominant Patients n = 16
Propulsion	6/7	6/16
Retropulsion	5/7	5/16
Segmentation	3/7	8/16

chi squared = 7·33

$0{\cdot}05 > p > 0{\cdot}02$

In proportion, Segmentation had a similar incidence in both groups. By contrast, Propagated contractions were significantly more common in the Diarrhoea Predominant group.

TABLE 26 Rate of propagated contractions in the IBS and control groups



B = Basal; St = Stimulated

TABLE 27

A comparison between the two IBS groups and the control group in the rate of spread of propulsive and retropulsive contractions before and after stimulation with Neostigmine.

Diarrhoea predominant IBS - Basal v Stimulated.
Rate of spread of contractions

Propulsive	t = 1·189	
	26 degrees of freedom	$0{\cdot}1 > p > 0{\cdot}05$
Retropulsive	t = 1·3767	
	12 degrees of freedom	$0{\cdot}5 > p > 0{\cdot}1$

Constipation predominant IBS - Basal v Stimulated.
Rate of spread of contractions

Propulsive	t = 1·065	
	33 degrees of freedom	$0{\cdot}5 > p > 0{\cdot}1$
Retropulsive	t = 0·2278	
	12 degrees of freedom	$p < 0{\cdot}5$

Control group - Basal v Stimulated.
Rate of spread of contractions

Propulsive	t = 2·777	
	15 degrees of freedom	$0{\cdot}02 > p > 0{\cdot}01$
Retropulsive	t = 3·4928	
	9 degrees of freedom	$p < 0{\cdot}01$

The control group showed the most difference before and after stimulation between the rate of spread of propagated contractions.

TABLE 28

A comparison between the diarrhoea predominant IBS and control group with respect to the rate of spread of propulsive and retropulsive contractions before and after stimulation with neostigmine.

Diarrhoea predominant IBS v Control group.

Basal. Rate of Spread

Propulsive	t = 2·8517 19 degrees of freedom	$p < 0{\cdot}02$
Retropulsive	t = 2·8797 14 degrees of freedom	$p < 0{\cdot}02$

Stimulated. Rate of Spread

Propulsive	t = 0·537 22 degrees of freedom	$p < 0{\cdot}5$
Retropulsive	t = 1·1437 7 degrees of freedom	$p < 0{\cdot}5$

There was a significant difference in the basal, unstimulated levels of the rate of spread of both the propulsive and retropulsive contractions in the control group compared with the diarrhoea predominant IBS group.

In contrast, there was no difference in the rate of spread of propagated contractions after stimulation with neostigmine.

TABLE 29

A comparison between the constipation predominant IBS and control group with respect to the rate of spread of propulsive and retropulsive contractions before and after stimulation with neostigmine.

Constipation predominant IBS v Control group.

Basal. Rate of Spread

Propulsive	$t = 1{\cdot}851$ 17 degrees of freedom	$0{\cdot}1 > p > 0{\cdot}05$
Retropulsive	$t = 5{\cdot}913$ 13 degrees of freedom	$p < 0{\cdot}001$

Stimulated. Rate of Spread

Propulsive	$t = 0{\cdot}265$ 31 degrees of freedom	$p < 0{\cdot}5$
Retropulsive	$t = 0{\cdot}065$ 25 degrees of freedom	$p < 0{\cdot}5$

There was a significant difference in the basal, unstimulated levels of the rate of spread of the retropulsive contractions in the control group compared with the constipation predominant IBS group.

In contrast, there was no difference in the rate of spread of propagated contractions after stimulation with neostigmine, nor in the case of propulsive contractions in the basal, unstimulated recordings.

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